PB82-107491

Options for Resource Recovery and Disposal of Scrap Tires. Volume 1

Urban Systems Research and Engineering, Inc.
Cambridge, MA

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Sep 81

U.S. Department of Commerce
National Technical Information Service
NTIS

PB82-107491

EPA-600/2-81-193
September 1981

OPTIONS FOR RESOURCE RECOVERY AND DISPOSAL OF SCRAP TIRES
Volume 1

by

Patricia L. Deese
James F. Hudson
Richard C. Innes
Douglas Funkhouser
Urban Systems Research & Engineering, Inc.
Cambridge, Massachusetts 02138

6-1/2"
9-1/8"

Contract No. 68-03-2725

Project Officer

Haynes C. Goddard
Solid and Hazardous Waste Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-81-193	2. ORD Report	3. RECIPIENT'S ACCESSION NO. PB82 107491
4. TITLE AND SUBTITLE Options for Resource Recovery and Disposal of Scrap Tires - Volume 1		5. REPORT DATE September 1981 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Patricia L. Deese, James F. Hudson, Ph.D. Richard C. Innes, Douglas Funkhouser		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Urban Systems Research & Engineering, Inc. 36 Boylston Street Cambridge, MA 02138		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-03-2725
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory - Cin.,OH Office of Research & Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED FINAL 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Project Officer - Haynes Goddard 513/684-4318

16. ABSTRACT

Currently over 200 million tires are discarded annually in the United States. In order to devise a means of dealing with this problem, an extensive background is given on the various technologies available for dealing with discarded tires. These technologies include: retreading; using whole tires for reefs, breakwaters, or barriers, and using shredded tires to produce asphalt-rubber. In addition, background is given on the use of both whole and shredded tires as fuel supplements. Cost analysis of asphalt-rubber and tire-derived fuel are presented in order to determine the feasibility of those two alternatives.

The tire market structure and the implications it holds for collection and resource recovery is important in all the technologies, and it is the main focus of the research. The goal of this report was to produce a list of public policy options and recommendations for dealing with discarded tires. The authors recommend a product charge on new tires with the charge revenues distributed to qualified disposers.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Recycling Scrap Tires Disposal Economics Asphalt Rubberized	Energy Recovery	Tires Disposal Economics	

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC (always the same)	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 151
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

BEGIN FIRST LINE OF TEXT HERE

TYPING GUIDE SHEET

CENTER OF PAGE

TOP OF IMAGE AREA

DROPPED HEAD; BEGIN SECTIONS HERE

DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

6-1/2"

9-1/8"

BEGIN LAST LINE OF TEXT

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

3/8"

PAGE NUMBER

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE

CENTER OF PAGE

TOP OF IMAGE AREA

DROPPED HEAD: BEGIN SECTIONS HERE

FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

The issue of competition between potential users of scrap tires is an important one. As the analysis that follows indicates, the high cost of transportation and handling make many recovery schemes practical only in urban areas where the concentration of used tires is high. However, most major urban areas have a network of jockeys and retreaders in place who are already collecting the tires which they can collect economically. While the economics for new uses, such as TDF or rubberized asphalt, may be very different, making a marginally greater number of tires economically usable, the new user will have to compete with the existing established industries for the easily collectable tires. While it may be possible to partially break into this existing network, major penetration is unlikely. Thus, in making detailed supply availability studies for the siting of any resource recovery facility to utilize tires, it will be very important to carefully estimate the existing used tire market in an area and to determine the actual cost of collecting marginal tires rather than assuming no competition.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

BEGIN LAST LINE OF TEXT

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

3/8"

PAGE NUMBER

ABSTRACT

Currently over 200 million tires are discarded annually in the United States. In order to devise a means of dealing with this problem, an extensive background is given on the various technologies available for dealing with discarded tires. These technologies include: retreading; using whole tires for reefs, breakwaters, or barriers, and using shredded tires to produce asphalt-rubber. In addition, background is given on the use of both whole and shredded tires as fuel supplements. Cost analyses of asphalt-rubber and tire-derived fuel are presented in order to determine the feasibility of those two alternatives.

The tire market structure and the implications it holds for collection and resource recovery is important in all the technologies, and it is the main focus of the research. The goal of this report was to produce a list of public policy options and recommendations for dealing with discarded tires. The authors recommend a product charge on new tires with the charge revenues distributed to qualified disposers.

This report was submitted in fulfillment of Contract No. 68-03-2725 by Urban Systems Research & Engineering, Inc. under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period October 1, 1978 to December 1, 1979, and was completed as of December 1, 1979.

6-1/2"
9-1/8
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

CONTENTS

Foreword iii
Abstract iv

1. Introduction 1
2. Summary and Conclusions 4
3. Tire Market Structure Implications for Collection and Resource Recovery 9
4. Technologies 45
5. Economics of Two Technical Options: Tire-Derived Fuel and Asphalt-Rubber Treatments 85
6. Public Policy Options and Recommendations 116

References 126

Appendix A. Assumptions for the Cost Analysis of Asphalt-Rubber . 142

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE
6-1/2"

SECTION 1

INTRODUCTION

THE SCRAP TIRE PROBLEM

Each year about 200 million passenger tires and 40 million truck tires are scrapped. Thie represents about 2.1 million tons of scrap passenger tires and roughly 1.9 million tons of scrap truck tires -- a total of 4 million tons (see Appendix A). Though a limited number of these scrap tires are used for resource and energy recovery, the vast majority go to landfills or dumps.

This report analyzes the market forces that influence scrap tire generation and disposal (Section 3), the technical options for resource recovery and environmentally sound disposal (Section 4), and the economics of the more promising resource recovery schemes (Section 5). In Section 6, public policy options are evaluated for their impact on scrap tire handling.

Tires are designed to last, and they do. To provide good performance under today's driving conditions, tires maintain their integrity under a wide range of conditions. Although the tread rubber may wear off, the tire casing with its cords, belting, and metal bead remains tough and flexible (see Appendix C). It is not surprising that scrap tires maintain the basic properties of a tire after they are discarded. Further improvements in durability and mileage appear possible and could reduce resource use (1). However, given current market trends, continuation of a significant scrap tire problem should be anticipated (see Section 3).

In this country, the various rubber reclaiming industries consume approximately 14 to 15 million tires a year (2). They produce products ranging from floor mats and gaskets to crumb rubber. Crumb rubber--very finely ground tire material with all steel and fiber removed--is utilized in various products such as asphalt rubber, or it is chemically devulcanized and substituted for new rubber. The primary user of the devulcanized rubber known as reclaimed rubber has traditionally been the tire industry. However, stringent specifications implemented to ensure the integrity of high performance, long-life radial tires call for little or no reclaimed rubber, which has greatly reduced the demand (3).

The collection and handling of scrap tires presents a series of problems which, when combined, are sufficient to warrant the careful evaluation of alternative public policy options:

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

- Loss of Resources - Products of the petrochemical industry make up the bulk of scrap tires. These materials represent a considerable resource, whether utilized as an energy source or as a raw material. As fossil fuels and petrochemical feedstocks become scarce, this resource will be increasingly important to the nation. As a supplemental fuel, the annual contribution of scrap tires could provide 0.11 quads (10^{15} Btu)--not a trivial percentage of the total annual U.S. energy consumption, which was 78 quads in 1978.

  Another equally important resource is landfill space. Tires are bulky, especially when landfilled whole. The critical cost factor in solid waste disposal is not the cost of operating existing disposal sites, but the incremental increase in acquiring the next site. Should scrap tires be occupying increasingly scarce landfill space?

- Difficulties in Tire Disposal - In addition to occupying space, scrap tires pose additional problems to operators of sanitary landfills. They must be handled separately if disposal is to be environmentally acceptable. Special techniques must be followed, such as placing tires together in the bottom of cells, or shredding tires before landfilling. Whole tires landfilled randomly with other solid wastes tend to rise to the surface, providing ideal refuges for rats, mosquitoes, and other vermin.

  Furthermore, including tires in landfills may seriously constrain the uses that can be made of completed landfill sites. Tires make poor fill; construction of facilities on top of landfill sites containing tires should be restricted.

  Environmentally acceptable disposal of scrap tires is costly. Because they are both strong and flexible, tires are expensive to shred. Many agencies have tried to offset the additional costs of size reduction by establishing a disposal fee.

  However, imposition of these fees can have an adverse impact on the effective disposal of tires. A large number of scrap tire disposers avoid paying any fees by using illegal or substandard dumping facilities, either directly or by hiring someone to take tires away. In urban areas, these scrap tires will frequently appear mysteriously on vacant lots. In rural areas, illegally discarded scrap tires may end up in ditches, wooded areas, or along the roadside.

- Health and Safety - In addition to the tires that are disposed of illegally, there are a significant number of tires that are held by the consumer or stockpiled by junk handlers and speculators. There are some potentially serious health and safety hazards posed by the presence of these tires in the environment.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

Fire: The threat to life and adjacent property posed by the potential of fire in scrap tire stockpiles must be considered. For example, two major stockpile fires have occurred in New England in the past few months.

Disease: Beside providing shelter for vermin at landfills, stockpiled tires have been directly implicated in significant public health problems. For example, in the rural areas of western Wisconsin, it has been determined that a strain of mosquito is carrying a form of encephalitis. Research has indicated that these mosquitoes, which generally live in tree holes in wooded areas, find suitable habitats in scrap tires around homes and barns. Since this type of mosquito has only a short flying range, these stockpiled tires bring the vector within easy range of both people and farm animals (4).

Tires can provide a protected habitat for rodents and insects that are commonly vectors for serious diseases. The social costs of proliferating these habitats may be significant, though it has seldom been recognized.

FATE OF SCRAP TIRES

Currently, the major options for the disposal of scrap tires include:

- Landfill in either municipal or private facilities. Currently, such facilities may not always be environmentally sound, but anticipated enforcement of new regulations should improve operations at such facilities.
- Traditional methods of resource recovery by tire splitting or rubber reclaim.
- Stockpiling of tires for future use, or simply because of a lack of any better option.
- Transporting of scrap tires to an area with less stringent standards (this is frequently an attractive alternative to local disposal).
- Illegal dumping as discussed above.
- Energy generation from tires, which is currently only being used as a disposal technique in a few special situations. There is increased interest in this resource recovery option.
- Various other alternative disposal techniques used on a small scale, such as reefs, breakwaters, barriers, planters, and, most important to the youth of the nation, swings.

9-1/8"

BEGIN LAST LINE OF TEXT

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

3/8"

PAGE NUMBER

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
9-1/8"

SECTION 2

SUMMARY AND CONCLUSIONS

KEY FINDINGS

The key findings of this study address the following important questions about the current and future handling of scrap tires. The conclusions reached are summarized in this section, and references are provided to the section of the report presenting the basis for each finding.

- o How many scrap tires are there?
- o Where are they and who owns them?
- o How many scrap tires will there be in the future?
- o What technical options exist for resource recovery?
- o Which options are economically competitive?
- o How do current public policies affect the handling of scrap tires?
- o Can disposal charges generate sufficient income to cover costs?
- o What changes in public policy will improve scrap tire handling?

Key Findings About the Tire Market

The investigations into the tire market focused on two questions: How do the new and retread markets affect the generation of scrap tires? And which participants in the tire market are responsible for ultimate disposal of tires? The tire market review produced the following key findings:

- o The number of tires scrapped each year is approximately equal to the number of new tires manufactured. Trends toward higher mileage radials in both truck and passenger tires will tend to reduce the number of scrap tires produced each year. This effect may be compounded in the case of passenger tires by an overall reduction in the number of miles traveled. Similarly, the trend to smaller cars will tend to reduce the mass of scrap tires generated in future years (Section 3).

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

- Current market trends may reduce the percentage of retreading. Currently, 45 percent of the retreaded passenger tires have snow tread configurations. However, trends toward smaller front wheel drive automobiles may reduce demand for snow tires. Industry experts expect the bias belted tires to be phased out and that the industry will offer radials as high quality tires and bias as the economy models. Currently 68 percent of the passenger car tire casings being retreaded are bias belted. There have been technical problems in retreading radials, which are increasing quickly as a portion of the new tire market. Radials require a larger capital investment, and the casings on existing radials have been difficult to retread because of problems in manufacturing quality control. It may, therefore, be difficult to provide a sufficient number of radial retreads to make up for the decrease in bias belted casings and retread sales (Section 3).

  All of these trends forecast a decrease in the amount of retreading, but there is a confounding factor. Since most new cars have original equipment (OE) radials, it is likely that replacement tires will also be radials. This is because individual bias-type tires cannot be substituted for radials, and also because suspensions are set for radial tires in new cars. To the extent that radial retreads compete with new radials rather than with low-cost bias tires, the market for retreads may be strong.

- Illegal disposal of scrap tires appears to be a common practice, particularly among small scrap tire handlers. A significant percentage of the scrap tires generated in the areas where disposal fees are in effect cannot be accounted (Section 3).

- Classical supply and demand analysis can be used to describe the price of scrap tires as a raw material for reclaim which reflects the costs of collection, storage and shipping. The number of scrap tires which are collected is to some extent determined by what the reclaim industries are able to pay for their raw material and still produce a competitive product. While there are some stockpiles of scrap tires throughout the country, all indications are that there are few if any untapped economically competitive sources of scrap tires. In almost all cases the holder of a scrap tire pays to have it removed rather than being paid for the resource (Section 3).

- The major cost in the collection of scrap tires at present is in the handling rather than the hauling fees. This may change as other sources are tapped (Section 3).

Technologies

The idea of recovering the resources in tires is by no means new. Three major industries currently utilize discarded tires: retreading, rubber

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

reclaiming, and tire splitting. Approximately 20 percent of the passenger tires and 30 percent of the truck tires in this country are retreads. Rubber reclaimers pulverize scrap tires, removing fabric and metals to produce crumb rubber which can be used in rubberized asphalt or can be devulcanized and used as a partial substitute for new rubber. Tire splitters manufacture items such as gaskets, floor mats, and parts for industrial equipment from split tire casings.

The reclaim industries (rubber reclaimers and tire splitters) consume approximately 15 percent of scrap tires produced each year.

Scrap tires are used as a fuel supplement by several tire manufacturers. These uses are frequently viewed as solutions to a disposal problem rather than as a major source of energy.

The technology review focused on assessing the potential of these commercially proven technologies, as well as many innovative unproven technologies, for utilizing some portion of the more than 3 million tons of tires disposed of each year.

- As the cost of new rubber increases, it is likely that the rubber reclaim and tire splitting industries will grow since their products will be more competitive with products currently made of new rubber. These industries may be able to pay a higher price for the scrap tires they use (Section 4).

- Any new scrap tire users will be competing with the existing uses for supply. Undoubtedly, the price paid for scrap tires will go up as demand increases.

- With a heat value of approximately 14,000 BTU/lb., scrap tires represent a valuable alternative fuel supply. The most promising technology for utilizing this resource is the simplest: shredding of scrap tires into a tire derived fuel (TDF) compatible for burning with coal. Research and practical experience have shown that few boiler modifications are required to grate systems, provided the mix does not exceed 10 percent TDF. There is at least one firm attempting to generate TDF for sale to a utility. The firm will be responsible for collection, shredding, stockpiling and shipping. Our economic analysis indicates that increased energy prices may make use of TDF economically attractive in the near future (Sections 4 and 5).

- Asphalt-rubber is more expensive than traditional road building materials. Manufacturers claim that the incremental costs will be outweighed by increases in the durability and performance of the product. The results, to date, of several demonstration projects currently underway are insufficient to verify these claims, but the potential is large (Sections 4 and 5).

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

- The proposed uses of whole tires in reefs, breakwaters, erosion control and barriers provide viable alternatives in special situations. While these applications should be encouraged where applicable, they cannot contribute significantly to the national solution of the disposal problem (Section 4),

Public Policy

The evaluation of current and proposed public policies reveals several interesting points about who pays for the disposal of scrap tires. Ideally, under the "User Pays" concept, the motor vehicle owner should pay for the disposal of scrap tires. While in some cases the user does pay indirectly, he almost never pays directly, and never perceives the disposal cost. If tires are disposed of in an environmentally unsound manner, the public bears the social cost. The public also bears the opportunity costs for lost resources and the administrative costs for implementing any proposed program. Therefore the goals of any public policy related to scrap tire handling have been identified as:

- Maximization of the overall benefit per unit of resource invested in passenger and truck tires, probably by increasing both new tire mileage and retreading.
- Encouragement of economical resource and energy recovery from scrap tires in preference to environmentally sound disposal.
- Reduction of the fraction of scrap tires which are disposed of in an environmentally unsound manner.

These objectives have been used to assess both existing and proposed public policy actions. The key findings of this review should be useful for policy makers concerned with improving resource management.

- The imposition of a disposal fee by a municipality tends to encourage illegal dumping. While very large scrap dealers tend to use legally acceptable final disposal techniques because of their high visibility, smaller operators appear to have multiple options for disposing of tires at lower costs than charged in municipal landfills.
- The cost of proper disposal of tires should be paid for by the motor vehicle owner. Since a vast majority of American housholds own automobiles, it may be rational to pay for disposal out of general tax revenues. Another alternative would be the imposition of a product charge on new tires which would be sufficient to cover the cost of environmentally sound disposal.
- There are various methods of distributing funds collected to cover the costs of environmentally sound disposal. Capital equipment grants could be used to offset initial costs but have little influence on the existing incentive structure. Bounties

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

paid to tire collectors would encourage tire collection but would not finance disposal operations. Funds for research, development, and demonstration have long term impacts on the alternatives available but like grants have little impact on the current market incentives. Operations and maintenance grants or service contracts to tire disposers (whether landfills or resource recovery firms) funnel directly into environmentally sound disposal operations.

CONCLUSIONS

The social cost of scrap tire disposal is currently being paid indirectly by an inefficient system. The durable tires present a serious disposal problem, and the cost of ultimate disposal should be incorporated into the cost of the new tire. Those firms currently utilizing scrap tires should receive payment for the service of tire disposal, which they are performing. This would correct market imperfections facing the tire user, the jockey, the retreader, and firms or agencies involved in resource recovery and disposal. It would reduce the large environmental burden of unsound disposal and increase the recovery of resource and energy from the 4 million tons of scrap tires discarded annually.

We, therefore, conclude that the most effective means of meeting public policy objectives of improved resource and energy recovery and environmentally sound disposal would be the implementation of a product charge system for the easy transfer of funds from tire users to tire disposal and resource recovery.

After a careful look at the many research, design, and development efforts throughout this country and the world, we further conclude that public policy objectives would be best met by supporting projects leading to the commercialization of resource and energy technologies. Demonstration projects and matching fund capitalized equipment grants would help get the resource and energy recovery industry mobilized to provide the disposal services needed.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

SECTION 3

TIRE MARKET STRUCTURE IMPLICATIONS FOR COLLECTION AND RESOURCE RECOVERY

These analyses show that the tire market is complex, with a number of actors and a complex network of interactions. While the new tire market is dominated by a few firms (16 firms produce new U.S. tires, and the five-firm concentration ratio is 76 percent), the retreading and disposal markets are much more widely dispersed, including service stations, individuals with pickup trucks, and others. The market structure affects the incentives of each of these actors, and changes in the incentives can greatly influence the recovery of resources from discarded tires.

This link between incentives and performance in the scrap tire market has been shown in many ways, including responses to new technologies such as radials, responses to transportation cost changes or local disposal fees, and the estimated profit and loss statements for jockeys. If there is one factor that becomes clear in the analysis, it is that the incentives--primarily economic, but also regulatory--affecting any portion of the tire production, distribution, consumption, and disposal system have major implications for the remainder of the system. The web is complex and highly interrelated, and it is important to evaluate policies through consideration of all those affected, not just those directly impacted.

This section addresses several aspects of the new and retread tire markets and the collection and handling of scrap tires. The first two subsections of Section 3 present background materials on new tires and retreads, with a focus on critical factors which influence the production and handling of scrap tires. Next, the interactions between new and retreaded tires in the replacement market are analyzed. The various participants in the scrap tire collection and handling process are also described. The effects of scrap tire disposal on the collection network are evaluated. A theoretical discussion illustrates that shifts in the cost of disposal (whether an increase or a decrease) will affect the incentives for both collection and inspecting for retreadability. Specific estimates of gross revenues and profits accruing to a typical jockey are calculated; and the final two subsections of this section deal with the cost of shipping scrap tires and the structure of the tire industry.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

THE NEW TIRE MARKET

There are four major categories of tires used in this country: Passenger, truck, farm, and off-road. Figure 1* illustrates the distribution of the annual total of over 255 million new tires among each of these groups. Farm and off-road tires, which make up only 3 percent of the market, are very specialized and contribute little to the overall scrap tire problem.

Passenger tires come in rim sizes of 12 to 15 inches and weigh anywhere from 15 to 30 pounds, with a generally accepted average of about 22 pounds. Truck tires come in rim sizes of 15 and 16 inches for light weight vehicles, and 15 to 24 inches for heavy vehicles. Light-duty truck tires weigh 30 to 60 pounds, while for heavy-duty tires the range is 90 to 200 pounds. Based on the total new tire shipment figures, an overall average weight for truck tires of 85 pounds will be used in this study. Thus, the overall weight of tires shipped is approximately 4.1 million tons with 2.2 million tons attributed to passenger tires and 1.9 million to truck tires. While the number of truck tires is small relative to the number of passenger tires, the total resources invested in the two categories of tires are similar. Since truck tires, particularly the heavy duty ones, are more difficult to handle and shred than passenger tires, they pose a significant problem for disposal.

Shipments of passenger and truck tires dropped off in 1974-1975 (Table 1) as a result of an industry strike and decreased auto production; since then, production has gradually increased to about the 1973 level. Industry projections for 1979 call for a drop of 8 percent in original equipment (OE) demand and an increase in the replacement market, with an overall decrease of about 3 percent.

The decrease in the OE market is clearly attributable to trends in the U.S. auto industry. While projections call for increased sales of replacement tires, these increases are less than might be expected if it were not for two compounding factors. The more common use of longer life radial tires on both passenger cars and trucks is reducing the number of replacements required. Similarly, reductions in the number of passenger miles traveled further reduces the need for replacement passenger tires.**

As the two graphs in Figures 2 and 3 illustrate, just over one quarter of the tires produced (both passenger and truck) are for installation on new vehicles (OE) while the remaining three quarters are for the replacement market. While the OE market is dominated by a few firms (Goodyear, Firestone and Uniroyal together control 75 percent of the OE passenger tire market)

---

*The Modern Tire Dealer's, "A Tire Industry Analysis," from which many of the graphics in this section have been adapted. There is a considerable amount of information on suppliers included in this annual analysis.

**Saul Ludwig, "Brighter 1979 to Ease Industry Woes?" Modern Tire Dealer, January 1979.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
9-1/8"

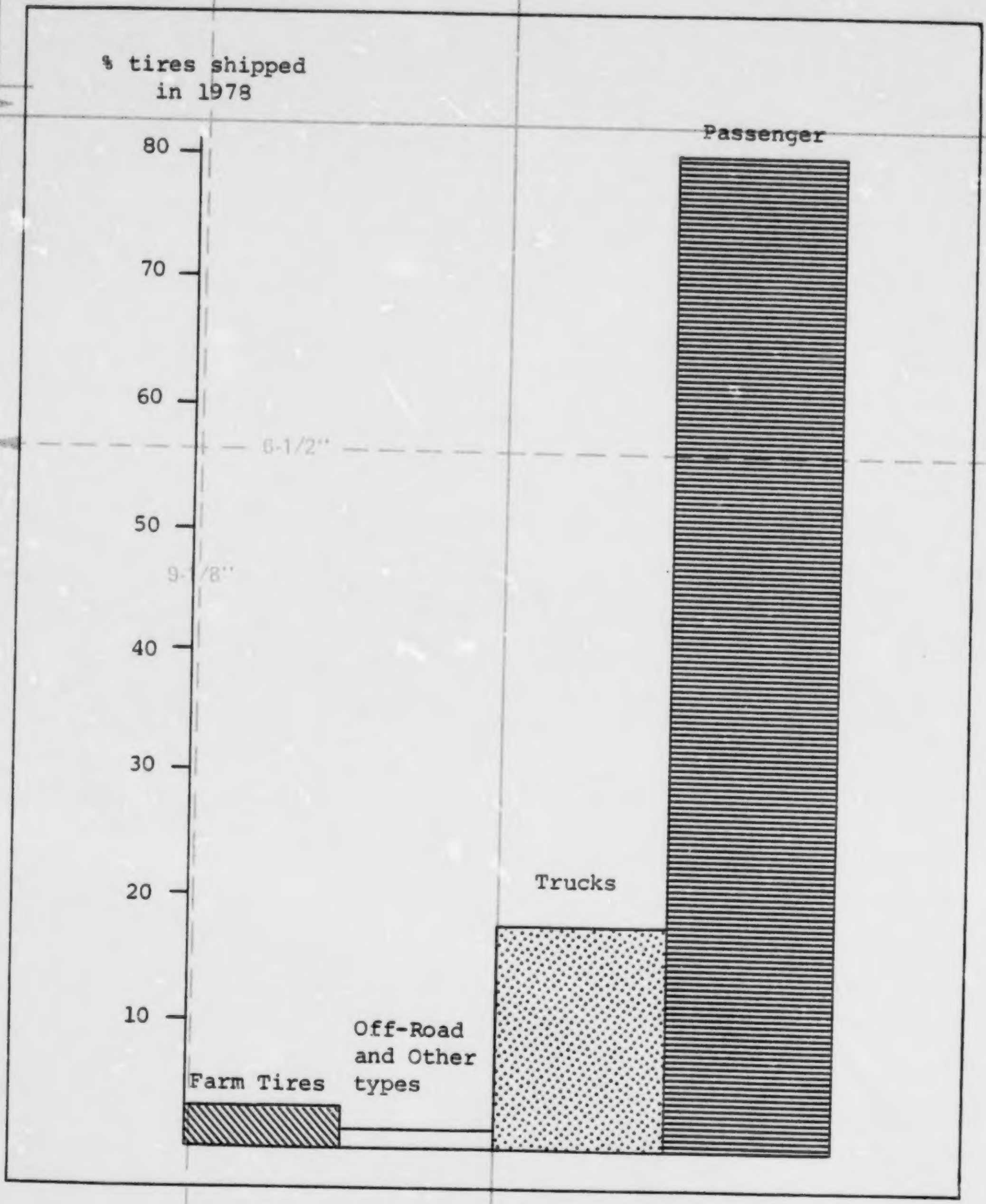


Figure 1. Profile of Tire Shipments.

SOURCE: Modern Tire Dealer, Bol. 60, No. 7, 1/24/79, p.30.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
9-1/8"

TABLE 1. PASSENGER AND TRUCK SHIPMENTS

(Includes domestic and foreign passenger and truck units)*
(In millions of units)

Type of tire	1978	1977	1976	1975	1974	1973
Replacement	179	167.5	160.4	150.4	155.8	171
OE	68.5	69.2	59.2	48.3	53.6	69

* SOURCE: Modern Tire Dealer, Vol. 60, No. 7, 1/24/79, p. 30.

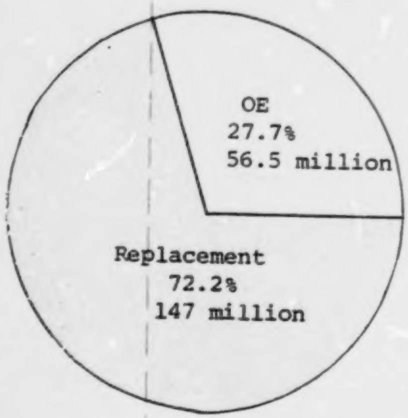


Figure 2. Passenger: Replacement Versus OE.

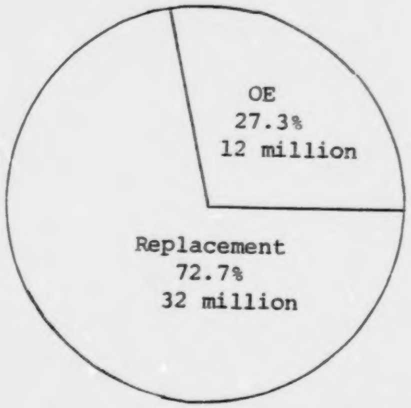


Figure 3. Truck: Replacement Versus OE.

SOURCE: Modern Tire Dealer, Vol. 60, No. 7, 1/24/79, pp. 26, 44.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

the replacement tire market is much more dispersed. A proliferation of brands in the replacement tire market has occurred with private brands such as Sears, Penney's, and Wards controlling a significant portion of the passenger (23%), light truck (16%) and heavy truck (6.7%) markets. There are basically three types of passenger tires currently being produced; bias, bias-belted, and radial tires, while truck tires generally have either a bias or radial configuration.

The breakdown of 1978 passenger tires, both OE and replacement by type of tire (Figure 4) highlights the dominance of radials in the OE market and the strength of inexpensive bias tires in the replacement market. These figures are even more important in view of the historical trends illustrated in Figure 5. While radials and bias tires have both increased their share of the market, bias-belted tires have dropped significantly. All indications are that this trend will continue and that the consumer will soon have only the choice between the more expensive, high-performance radial and the inexpensive lower mileage bias tire.*

Tire technology is constantly changing. Transitions have been made from the bias to the bias belt and now to the radial with progressive improvements in performance and durability. Many future improvements can also be anticipated. Projections have been made for a 100,000 mile tire as well as for single material molded plastic tires. While the majority of radials are steel-belted (Tables 2 and 3), industry projections call for an increased use of rayon, fiberglass and aramid. Steel replaced by advanced man-made fibers is important due to difficulties in bonding rubber to the steel which increases chances of edge separation. Another current technology shift is the introduction of the elliptical tire which has a lower aspect ratio and is expected to give higher performance, longer mileage and better gas mileage. Currently, elliptical tires are not provided as OE on any new vehicle and are at a disadvantage in the replacement market because specialized larger diameter rims are required. However, industrial experts feel that the performance features of the elliptical tire will insure its gradual entry into the market, somewhat similarly to the entrance of the radial.

---

*NTDRA Dealer News, September 10, 1979, p. 77, reported industry plans to increase radial production and the closing of three bias tire plants.

EPA-287 (Cin.)
(4-79)

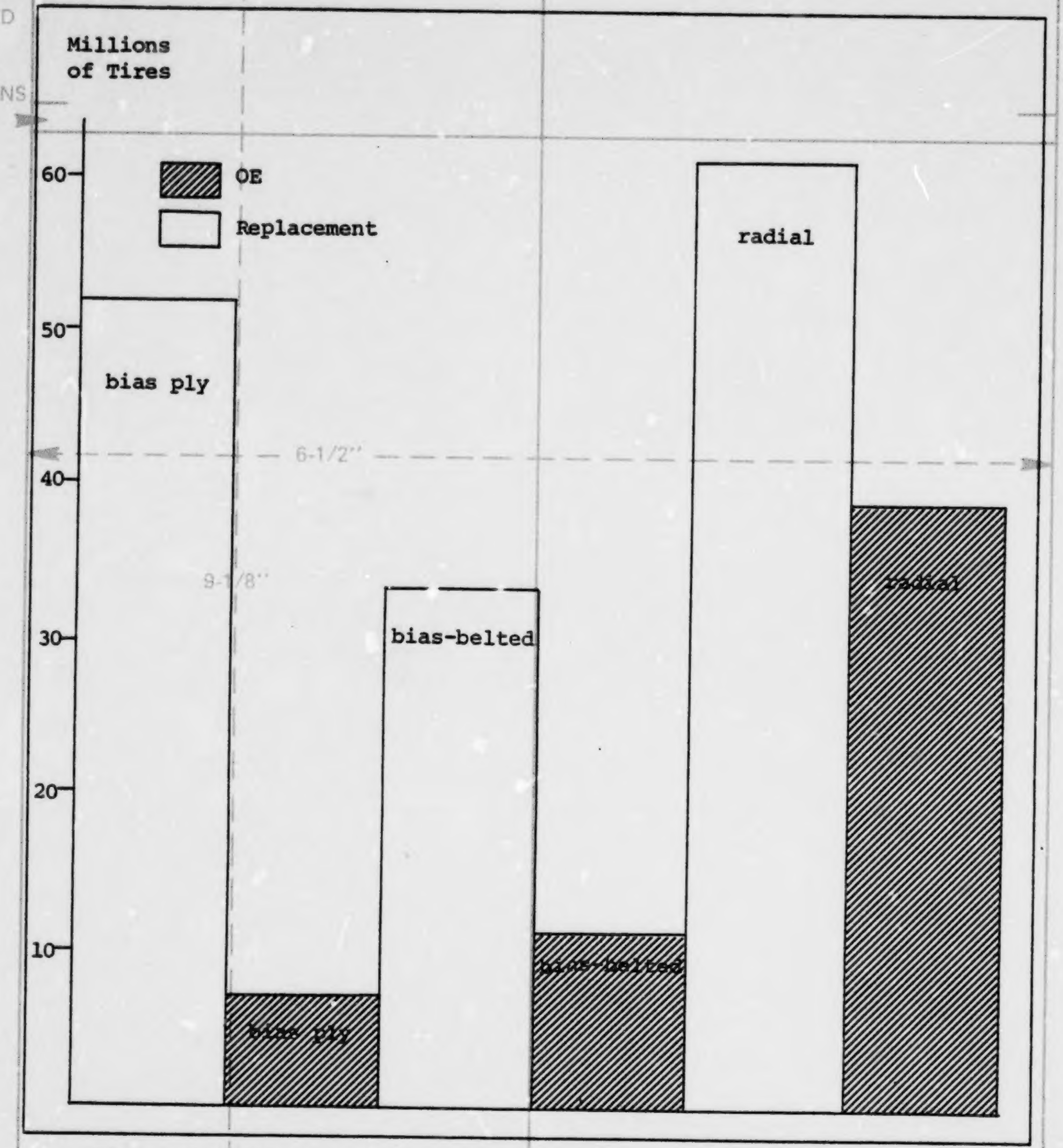


Figure 4. Estimated number of tires shipped in 1978 for OE and replacement markets.

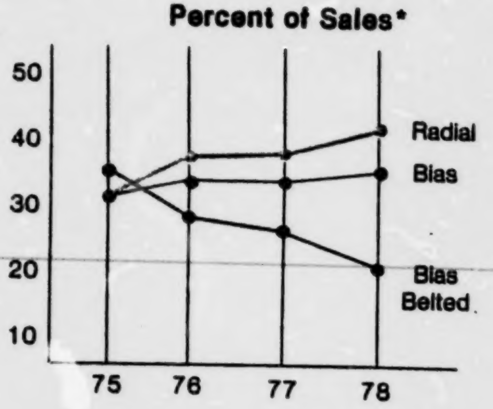
SOURCE: Modern Tire Dealer, Vol. 60, No. 7, 1/24/79, p. 26.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
6-1/2"
1/8"

Retail Prices for New Tires and Sales Distributions

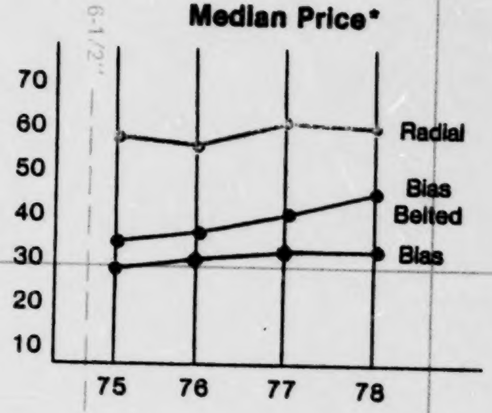
The accompanying chart and tables track the history of median tire prices (bias, bias belt and radial) and distribution over a four year period. Notable is the increasing median price of the bias belt tire and the decline of the bias tire as a percent of sales.



Distribution by percent of sales

	1978	1977	1976	1975
Bias	35.8%	34.3%	34.4%	31.7%
Bias Belt	22.0%	28.7%	29.6%	36.6%
Radial	42.2%	37.0%	36.0%	31.7%

*Source NTDRA



Median Retail Prices

	1978	1977	1976	1975
Bias	$32.50	$32.50	$29.81	$29.42
Bias Belt	47.50	42.50	37.02	34.98
Radial	62.50	62.50	58.48	59.40

Figure 5

SOURCE: Modern Tire Dealer, Vol. 60, No. 7, 1/24/79, p. 27.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Reinforcement Materials

TABLE 2. CORD

	OE			Replacement		
	Polyester	Nylon	Rayon	Polyester	Nylon	Rayon
Bias	95%	4%	1%	98%	2%	0%
Bias-Belt	100%	0%	0%	99%	0%	1%
Radial	95%	0%	5%	92%	0%	8%

TABLE 3. BELTING

	OE				Replacement			
	Steel	Rayon	Fiber-glass	Aramid	Steel	Rayon	Fiber-glass	Aramid
Bias-Belt	0%	0%	100%	0%	3%	1%	96%	0%
Radial	87%	1%	12%	0%	76%	7%	13%	4%

SOURCE: Modern Tire Dealer, Bol. 60, No. 7, 1/24/79, p. 34.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

3/8"

PAGE NUMBER

EPA-287 (Cin.)
(4-76)

RETREADS IN THE REPLACEMENT MARKET

Retreaded tires have always played a role in the replacement tire market. While there has been some consumer concern over safety of passenger retreads, reputable dealers can sell as many retreaded tires as they can make. Production is currently limited by the supply of usable, reasonably priced casings. As illustrated in Table 4, the annual production of retreads has remained relatively constant in recent years.

Perhaps the biggest problem facing the retreading industry is the modifications which are necessary to keep up with the changing tire technologies. As the graphs in Figure 6 illustrate, the retreading industry is in a state of transition with only a fraction of its production (12%) in the most popular construction type for OE, the radial. The transition from bias and bias belted to radial tires has had a significant impact on the retread industry, which must deal with a new raw material, retooling and marketing of a new product.

From the data presented in Table 4 and Figure 6, it is possible to summarize the current state of the retread industry in this country. A total of 13.6 million truck tires and 31 million passenger tires are retreaded each year. However, this constitutes less than 20 percent of the total replacement tire market of 223.6 million tires per year. Although retread rates are higher for truck tires (30%) than passenger tires (18%), it is clear that the vast majority of both truck and passenger tire casings are scrapped after one life.

Tread configuration is also an important factor in the marketability of retreads. As highlighted in Figure 7, there are basically two tread configurations: conventional and snow/mud. Although the bad winters of 1977 and 1978 resulted in an increase in snow tire purchases aiding the retread industry, current automobile trends toward front wheel drive and OE radials may reduce snow tire purchases in the long term. The only potential good news for retreaders is that more cars come with OE radials. Consumers purchasing snow tires and wishing to be consistent are likely to purchase retreaded radial snow tires.

The technical problem of increasing the number of radial retreads has been mentioned and is discussed in Section 4. Even assuming the technical problems can be overcome, there are additional marketing problems as well. A current conventional (bias-belted) retread sells for about $24, with $26 charged for a snow retread. Retread radials sell for $28 to $31. The current median price for bias tires is $32.50, while new radials sell for an average of $62.50. When compared to a new radial, a retreaded radial with an expected mileage of 80 percent of a new radial, is an excellent buy. However, a new bias tire is competitively priced with retreaded radials. Although they are not perfect substitutes, new bias tires will be competing with retreaded radials for a portion of the replacement market.

TABLE 4. TOTAL PASSENGER TIRE REPLACEMENT

(Includes new passenger tires and retreads)*
(In millions of units)

	1978	1977	1976	1975	1974	1973
New Tires	147	139	137	129	133	150
Retreads	31	33	35	34	36	35

*SOURCE: Modern Tire Dealer, Vol. 60, No. 7, 1/24/79, p. 30.

6-1/2"
9-1/8"

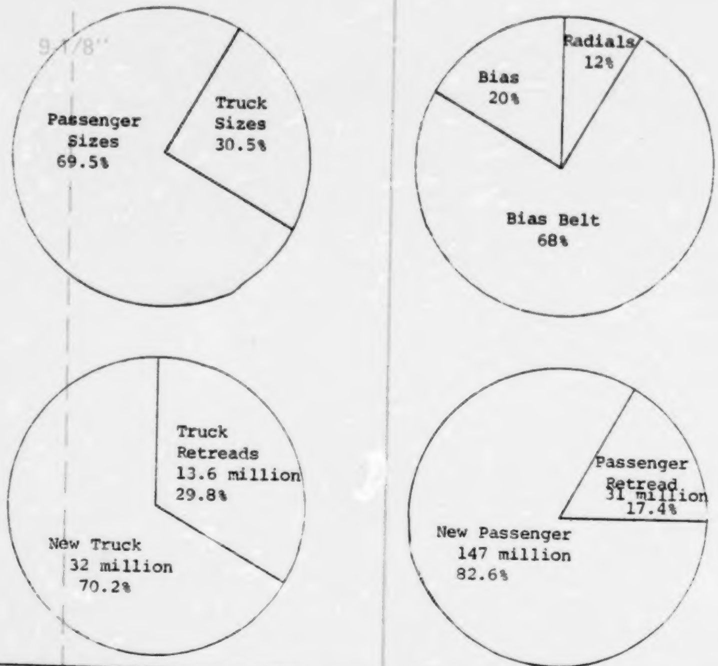


Figure 6 Overview of Retread Market. (1978)

SOURCE: Modern Tire Dealer, Vol. 60, No. 7, 1/24/79, p. 46.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
9-1/8"

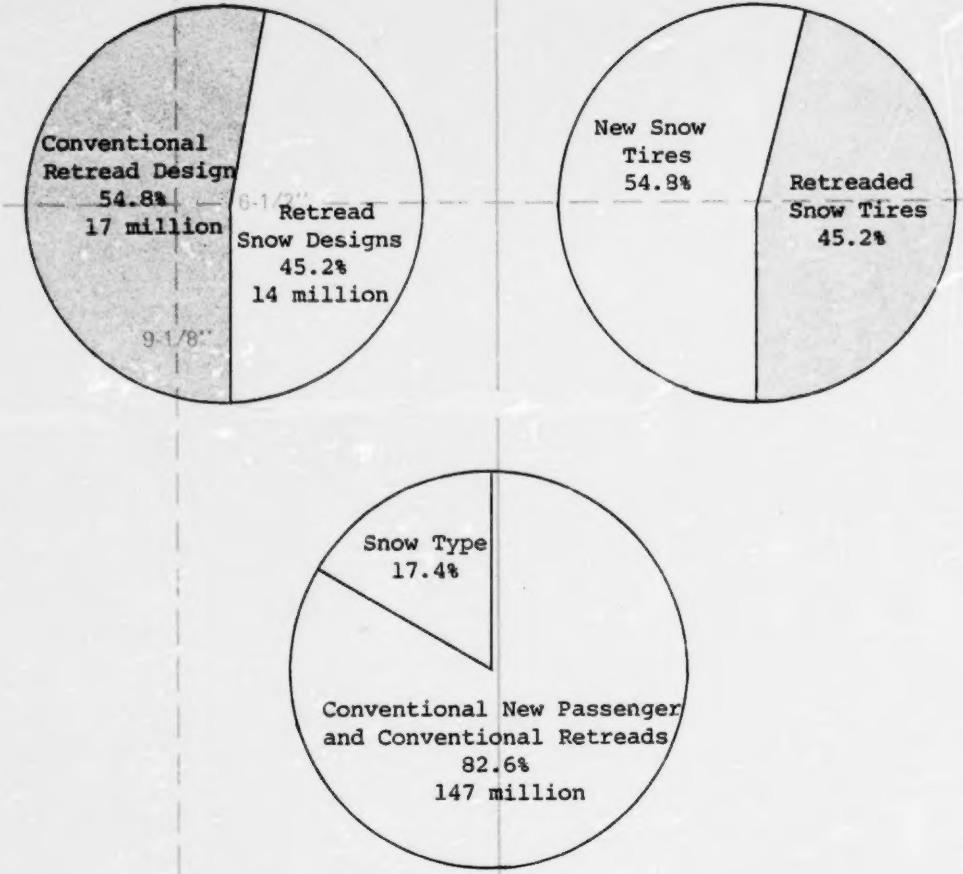


Figure 7 Snow Tires

SOURCE: Modern Tire Dealer, Vol. 60, No. 7, 1/24/79, p. 50.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

INTERACTIONS IN THE REPLACEMENT MARKET

Both new and retreaded tires play significant roles in the tire replacement market and an understanding of the interaction between the two is vital for projecting the size and character of the scrap tire market. The introduction of the radial tire has had and will continue to have a significant impact on both the new and retread tire market and on scrap tire generation. As new tire technology changes, there is a lag time of one tread life before the new tires are discarded and become casings available for retreading. Thus, a first tread scrap tire is likely to be about two years old while a second tread scrap tire is usually three to four years old. Thus current trends in the new tire market will have impacts on the scrap tire problem for years to come.

Using the various production figures previously presented, an overall materials flow model of the tire industry has been developed. Figure 8 summarizes this concept which is based on the steady state assumption that the total tire stock will remain roughly constant. While there are in reality minor fluctuations, this assumption is reasonable for an examination of gross tire flows. For example, there are indications that during the 1974-1975 recession, while consumers may have pushed for a few extra miles, the total number of tires on the road remained constant.

Using The Modern Tire Dealer's figures for passenger tire production for 1978 and multiplying each tire type by an expected mileage figure from Tables 5 and 6, an estimated 10,000 miles/year results in an estimated total passenger tire stock of 515 million tires. This figure is very similar to our earlier estimate of 520 million which was based on a 2 to 3 year turnover, registration of 100 million vehicles, and approximately 6 tires per vehicle.

Another assumption is that the first tread tires which are sold as used tires (without retreading) are considered to have never really left the first tread tire stock. This simplification permits the reviewer to concentrate on the major interactions between new and retreaded tires. The model also assumes that no tire is retreaded more than once. While a very small number of truck tires are re-retreaded, several more than once, the assumption is accurate for the vast majority of both passenger and truck tires.

Interpreted on its most simplistic level, this model simply states that the number of tires scrapped is approximately equal to the number of new tires produced.

Assuming steady state, the change in the total tire stock equals zero and:

$$A + R = D + S$$

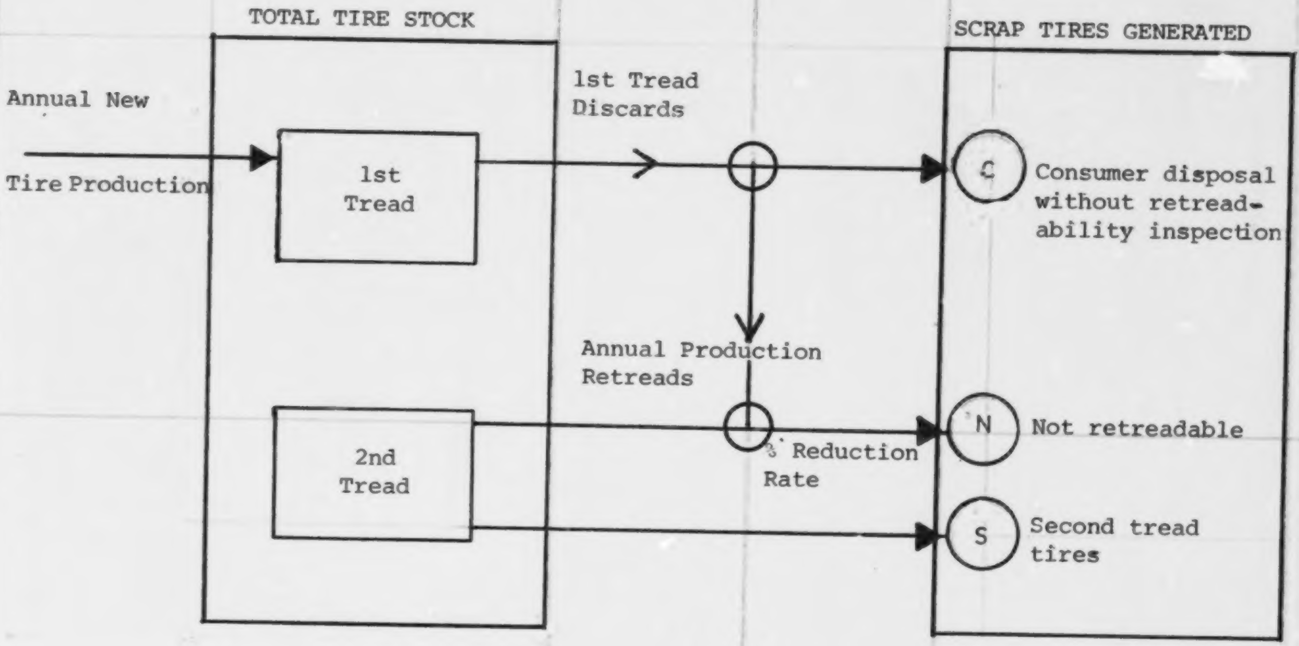
$$D = C + N + R$$

$$A = C + N + S$$

This simplistic approach has been used to develop projections for the total scrap tire production given earlier in this report. However, the model can

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTION HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)


TOTAL TIRE STOCK
SCRAP TIRES GENERATED
Annual New
Tire Production
1st Tread
2nd Tread
1st Tread Discards
Annual Production Retreads
% Reduction Rate
C
Consumer disposal without retreadability inspection
N
Not retreadable
S
Second tread tires

Change in the Total Tire Stock $= A + R - D - S$

Consumer Disposal Rate $= C/D$

Retreadability Rate $= \frac{R}{D - C}$

Total Scrap Tire Production $= C + N + S$

Figure 8. Retreading.

TABLE 5. PASSENGER TIRE CONSTRUCTION TYPES

Year	Type	OE	Replacement
1977	Bias	11%	36%
	Bias Belt	22%	26%
	Radial	67%	38%
1978	Bias	13%	35%
	Bias Belt	18%	23%
	Radial	69%	42%
1979	Bias	15%	32%
	Bias Belt	11%	20%
	Radial	74%	48%

SOURCE: Modern Tire Dealer, Vol. 60, No. 7, 1/14/79, p. 26.

9-1/8"

TABLE 6. CURRENT MILEAGE ESTIMATES

Tire Type	New	Retread
Bias	16,000	13,000
Bias-belted	20,000	16,000
Radial (U.S.)	28,000	22,000
Radial (foreign)	38,000	30,000

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA: OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

be used on a more detailed level to provide useful insights into impacts of changing tire technologies and future scrap tire generation.

Because of limited data, more detailed analyses of the truck tire market have not been performed. However, if one assumes a consumer disposal rate for truck tires of 5 percent, a reasonable number based on our interview results, it can be estimated that the retreadability rates for truck tires are just over 30 percent. Industry experts attribute the relatively high retreadability rates of truck tires to the improved maintenance commercial vehicles receive.

Data on passenger tires presented in Tables 5 and 6, when combined with information presented earlier, provides a basis for a much more detailed examination of that market. The most important question raised is what impact will the shift to radial tires have on the retread sector and in turn on the scrap tire generation. If fewer tires are retreaded, more new tires will be required to maintain the tire stock and consequently more tires will be scrapped.

If one assumes the average first tread tire is discarded after two years, D in 1978 must be approximately equal to A in 1976 both in magnitude and distribution of tire types. Thus in calculating retreadability rates, 1978 retread production figures for R should be compared to 1976 new tire production figures for D. Using this approach and an estimated consumer disposal rate of 10 percent, the 1978 retreadability rates have been estimated (Table 7).

Table 8 shows the estimated 1980 retread production if retreadability rates are the same as 1978. Thus if retreadability rates remain the same, the retread production would drop from 31 in 1978 to 28.6 in 1980. Further shifts away from bias belted tires would have even more severe impacts on the retread production. Table 9 presents calculations for a hypothetical year in the 1980's in which bias belted tires make up only 10 percent of production (as opposed to the current rate of 22 percent). Based on a total production equal to 1978 and applying the estimated 1978 retreadability rates, retread production would drop to 22.7 million.

However, it is unrealistic to assume that retreadability rates will remain at the current rates. One must assume that the quality of U.S. retreads will improve and that more shops will be upgraded to handle radials. It is equally interesting to pose the question in terms of changes in the retreadability rates required to maintain the 1978 production levels of 31 million retreaded tires. Tables 10 and 11 indicate the estimated retreadability rates required. It has been assumed that increased retreading will be split 70 percent to radials and 30 percent to bias. This assumption has been made because significant improvements in bias retreadability should not be anticipated.

These results indicate that a drastic increase in radial retreading capacity must be achieved in a short time if the retreading industry is to continue contributing at its current level to this country's tire stock. Any real increase in overall retreading capacity would require at least a tripling of the current retreadability of radial tires.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

TABLE 7

1976 New Passenger Tire Production		Estimated 1978 Retreadability Rates	1978 Retread Production (millions)
Casing Type	Million Tires		
Bias	64.3	10.8%	6.3%
Bias-belted	55.3	42.0	21.0
Radial	67.4	6.0	3.7
TOTAL	187.0	18.4%	31.0

Assumption: Consumer Disposal Rate = 10%

Casings available for retreading in 1978 were those produced in 1976.

TABLE 8

1978 New Passenger Tire Production		Estimated 1978 Retreadability Rates	Estimated 1980 Retread Production (millions)
Casing Type	Millions Tires		
Bias	72.8	10.8	7.1
Bias-belted	44.7	42.0	16.9
Radial	85.8	6.0	4.6
TOTAL	203.3	15.6	28.6

Assumption: Consumer Disposal Rate = 10%.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 9

Casing Type	Hypothetical Year: New Tire Production (millions)	Estimated 1978 Retreadability Rates	Hypothetical Year: New Tire Production (millions)
Bias	70.8	10.8%	6.9
Bias-belted	20.0	42.0%	7.6
Radial	112.7	6.0%	6.1
TOTAL	203.5	11.2%	20.6

Assumption: Consumer Disposal Rate = 10%

TABLE 10

1978 New Passenger Tire Production		Required 1978 Retreadability Rates	1978 Retread Production (millions)
Casing Type	Millions Tires		
Bias	72.8	11.9%	7.8
Bias-belted	44.7	42.0%	16.9
Radial	85.8	8.2%	6.3
TOTAL	203.3	16.9%	31.0

Assumption: Consumer Disposal Rate = 10%.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE
6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA 287 (C.n.)
(4-78)

TABLE 11

Hypothetical 1980's New Passenger Car Tire Production		Required Retreadability Rates, Hypothetical Year + 2	Desired Retread Production, Hypothetical Year + 2
Casing Type	Millions Tires		
Bias	70.8	15.4%	9.8
Bias-belted	20.0	42.0%	7.6
Radial	112.7	13.4%	13.6
TOTAL	203.5	16.9%	31.0

Assumption: Consumer Disposal Rate = 10%.

SCRAP TIRE HANDLING

In the cases where a consumer is purchasing a new replacement tire, the old tire is frequently taken by the retailer as a "trade in" (with an actual negative value to the retailer). In an increasing number of situations, the retailers are not volunteering to handle discarded tires and may even refuse to take them. This appears to be particularly true of smaller retail outlets such as service stations. In these instances where the consumer retains scrap tires it is unclear what method of final disposal is most common. However, indications are that these consumer-retained discarded tires are rarely retreaded and are frequently scrapped in an environmentally unacceptable manner.

Small retailers, who frequently handle tires only as a sideline, and therefore do not want to be bothered by problems of inspection and disposal, often make informal arrangements with a tire broker to provide these services. The term "jockey" or broker applies to people who collect discarded tires from various outlets, grade them for retreadability and other uses, and dispose of all the scrap tires. The brokers range in size from national operations to individuals with a ten year old pickup truck. While the large brokers must dispose of scrap tires legally because of their volumes and visibility, indications are that the smaller operations almost never dispose of tires within the legitimate system

EPA-287 (Cin.)
(4-76)

Once discarded tires reach a retread shop, they have usually been inspected at least once. Tires with sufficient tread may be removed for resale as used tires, and tires which are clearly not retreadable will be scrapped. However, at a retread shop a more careful inspection results in the scrapping of additional tires. Retread shops may scrap anywhere from one to five tires for every one which they retread, depending on how rigorous the preliminary screening is, and on their sources of supply.

This description of the scrap tire market seems quite straightforward: retailers have the jockeys collect their tires; the jockeys then give the apparently retreadable ones to the retreaders and scrap the rest; and the retreaders scrap the unusable ones and retread the remainder. However, as Figure 9 illustrates, the system is made more complex with jockeys selling to jockeys, retreaders doing their own collections, some new tire manufacturers providing retreading services for their dealers, tires being transported to Mexico where standards are less rigorous, retreaders are selling tires which fail inspections to other retreaders with lower standards and so on.

In a telephone survey which was conducted to try to gain a better understanding of the scrap tire market, it was learned that a large number of the one-man jockey operations remain anonymous even to their clients, both retailers and retreaders. These operations also operate on no particular schedule. The methods these jockeys use for disposal of scrap tires vary from location to location. In all instances, the scrap tire has very little economic value relative to a retreadable casing; generally a price must be paid to have scrap tires hauled away. The holder of a scrap tire will almost always seek the lowest cost disposal option.

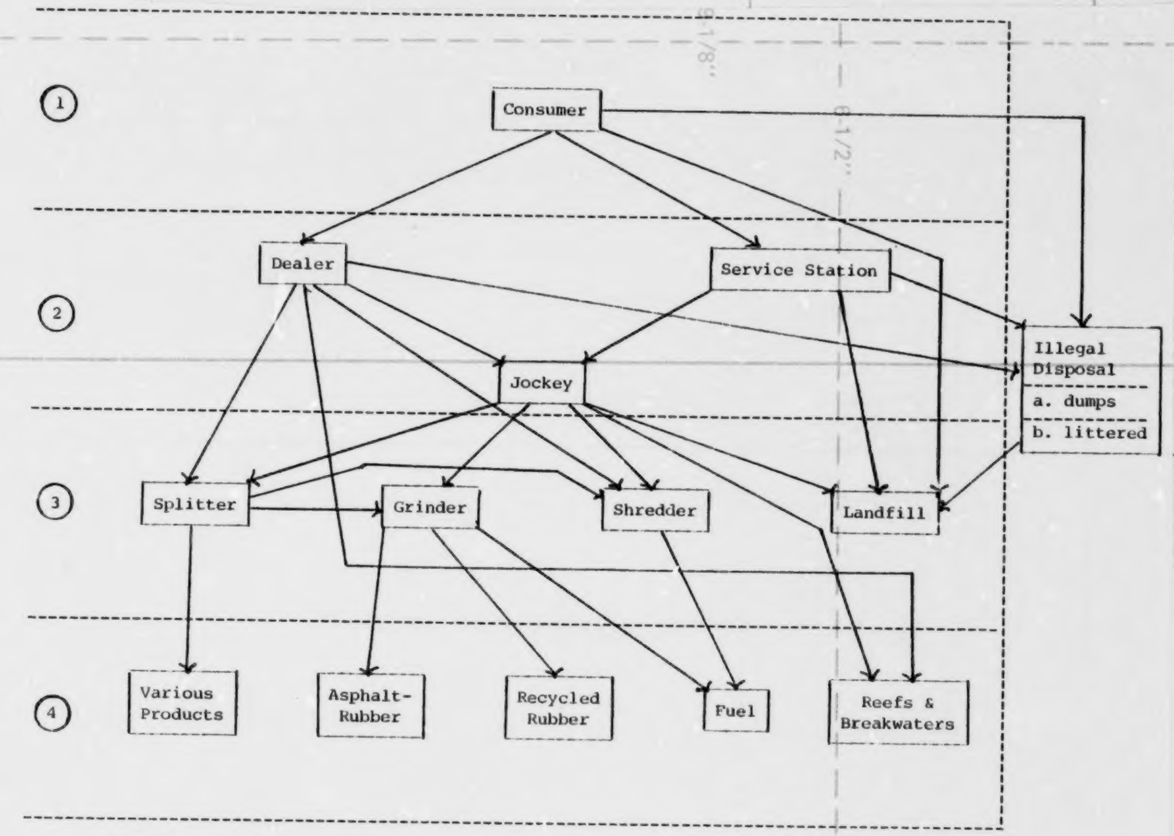
The currently widely-used options for the disposal of scrap tires include:

- Legal landfill in either municipal or private facilities. Practices at such facilities may not at present be environmentally sound, but anticipated enforcement of new regulations should improve operations at such facilities.
- Traditional resource recovery by means of either tire splitting or rubber reclaim.
- Stockpiling of tires either for future use or because of a lack of anything better to do with them.
- Transporting scrap tires to an area of less stringent standards (frequently an attractive alternative to disposal).
- Illegal dumping in vacant lots in cities, ditches or wood lots in rural areas.
- Energy generation, which is currently used only as a disposal technique in a few situations usually by tire manufacturers. There is increased interest in this resource recovery option.
- Various other alternative disposal techniques are used on a small scale and are not likely to provide a means of disposal for a significant number of scrap tires. These include reefs, breakwaters, barriers, planters, and (most importantly) swings.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD: BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
9-1/8"
6-1/2"


①
②
③
④
Consumer
Dealer
Service Station
Illegal Disposal
a. dumps
b. littered
Jockey
Splitter
Grinder
Shredder
Landfill
Various Products
Asphalt-Rubber
Recycled Rubber
Fuel
Reefs & Breakwaters

Note: Does not include retreading since it does not lead directly to disposal.

Figure 9

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER

EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE TYPING GUIDE SHEET CENTER OF PAGE TOP OF IMAGE AREA DROPPED HEAD: BEGIN SECTIONS HERE

IMPACT OF A CHANGE IN DISPOSAL COSTS ON THE SCREENING OF DISCARDED TIRES

It is important to consider the impact of disposal costs on retreading, which is the most desirable option for suitable casings. A significant fraction of the tires are inspected and for each a decision is made either to retread or scrap it. Where this decision is made by someone other than the retreader, there is room for error and consequently the costs of errors affect the decision process. We can imagine a system where the dealer, service station operator or jockey is faced with classifying a tire as either a scrap or retreadable casing. He knows his classification is with error and that there is some chance that a scrapped tire will actually be retreadable and that a tire sent to the retreader may not be suitable for recapping.

The problem has been depicted by the model shown in Figure 10. The tire is classified as either a scrap or retreadable casing based on an estimate of its condition c (an arbitrary indicator of retreadability). If a discard is incorrectly classified as a retread, the cost to the dealer is (d+ t), the sum of d the disposal cost and t the cost of transporting a scrap casing to the retreader in place of a retreadable carcass.* A correctly identified retreadable carcass brings a profit of v. A carcass incorrectly identified as scrap carries a loss equal to the sum of the disposal cost and the opportunity loss of the value of the retreadable carcass, d + v. If the tire is correctly classifed as a scrap, the cost to the agent is d.

Based on the estimate of the tire's condition, there is a probability of correct classification if the tire is classified as a retreadable casing--$P_r(c)$--and similarly a probability of correct classification if the tire is classified as scrap, P(c). There is some cutoff condition c (called the marginal condition below) such that the expected gain to the jockey from classifying the tire as a retreadable casing just equals the expected gain from classifying it as a discard. The marginal condition c is defined implicitly by the relationship:

$$P_r(c)V = (1-P_r(c))(d + t) = -P_s(c)d - (1-P_s(c))(d + v) \qquad (1)$$

There are several interesting implications of this model. First, c the marginal condition for the jockey most likely does not equal the minimum acceptable condition for retreading, c*. This situation is depicted in Figure 11. In the case of c_1* the dealer sends tires to the retreader which cannot be recapped, and society suffers a loss equal to the unnecessary transportation and handling costs. In the case of c_2 some retreadable tires are not sent to the retreader and we suffer a loss equal to the disposal cost of those tires plus their value as retreadable casings.

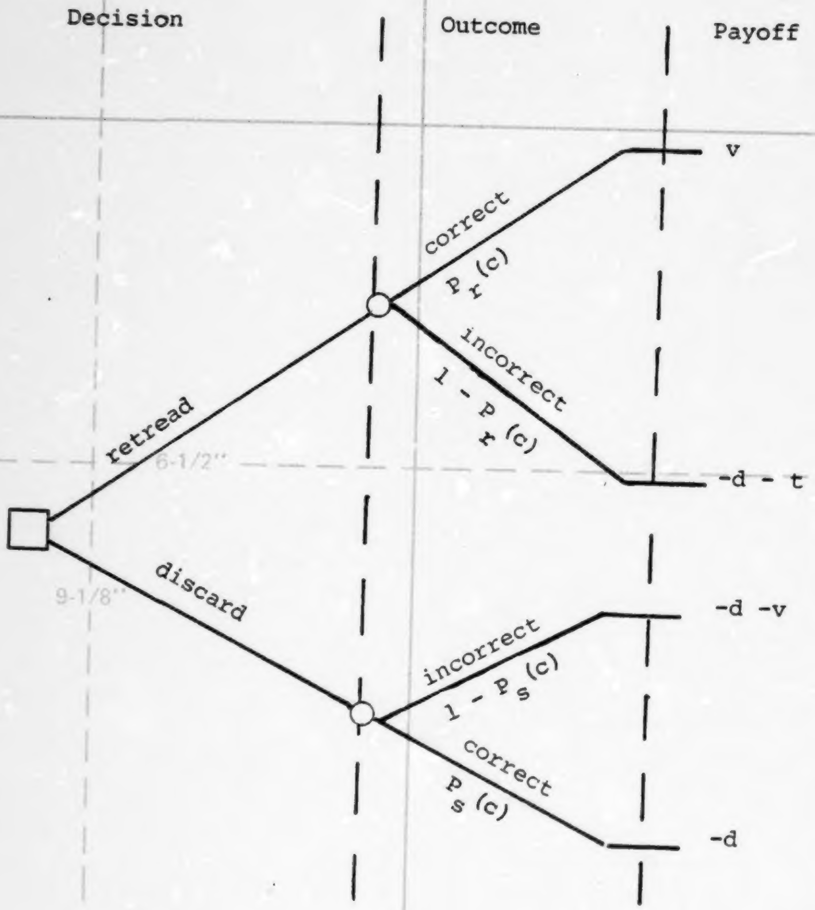
Changing the disposal cost will alter the marginal condition and therefore alter the number of tires sent by the jockey to the retreaders. By differentiating (1) with respect to d and solving for $\frac{dc}{dd}$, the impact of changes in disposal costs can be seen.

---

*We assume the dealer remains responsible for disposal.

EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
9-1/8"


Decision
Outcome
Payoff
retread
correct
P_r(c)
v
incorrect
1 - P_r(c)
-d - t
discard
incorrect
1 - P_s(c)
-d -v
correct
P_s(c)
-d

c = indicator of condition

$P_r(c)$ = probability tire is a retread once it has been classified as a retread, $\frac{dP_r}{d\,c} > 0$

$p_s(c)$ = probability tire is a discard once it has been classified as a discard, $\frac{dP_d}{d\,c} < 0$

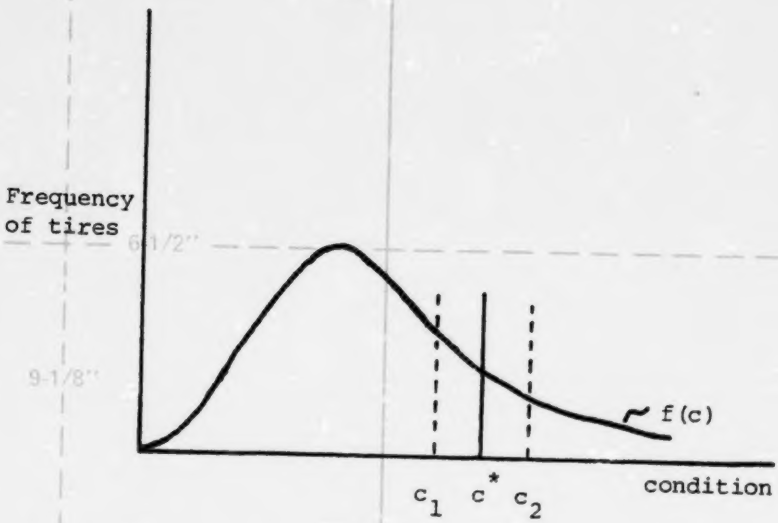
(t) = cost of hauling discard to a retreader

v = profit

Figure 10. Discard/retread decision analysis

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)



c^* = minimum acceptable condition for retreading.

Figure 11. Frequency distribution of tire conditions showing marginal condition.

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

The calculations give:

$$\frac{dc}{dd} = \frac{-p_r}{\frac{dp_r}{dc}\,[v + d]} \qquad (2)$$

Thus, a reduction in the disposal costs will tend to increase the jockey's marginal condition, that is the inspected casing must be of higher quality before he can risk the additional cost of transporting it to a retreader. If the disposal costs are increased, the opposite is the case; the jockey's marginal condition decreases, thus reducing the quality constraints on tires sent to retreaders. The impacts of either raising or lowering the disposal costs depend in part on the state of the market prior to the change.

If we are currently at c_1 where the jockey's marginal condition is lower than c*, and disposal costs are lowered, social welfare will improve by the elimination of excess transporting of unretreadable tires. Improvement will occur until c is pushed past c*. However, if we are operating at c_1 and if disposal costs are increased, the variance between c and c* will only be increased. Thus, jockeys would risk sending tires of even a lower quality to the retreaders and social welfare would be reduced by the amount of extra transportation costs incurred.

If our operating point is c_2, the jockey's marginal condition is higher than c*, so that he can afford to dispose of a number of retreadable casings. If in this situation the disposal costs were reduced or eliminated, then the variance between c and c* would increase and the jockey could afford to discard an even greater number of retreadable casings with a decrease in social welfare. If in this situation the disposal costs are increased, the variance between c and c* decreases and the jockey is forced to send a greater number of tires of lesser quality to the retreader for inspection. Social welfare will increase until c is pushed past c* in which case the cost of transporting unretreadable casings is greater than the value of retreadable casings.

6-1/2"

The above analyses assume that the retreaders' minimum acceptable condition c* remains constant. In practice the retreader becomes responsible for the disposal of casings which fail inspections during the retreading process. In most shops this rejection rate is anywhere from one to four tires out of five. Thus changes in the disposal costs will have a significant impact on the retreaders willingness to take marginal casings. If the disposal costs are increased, c* will most likely increase; while conversely if disposal costs decrease, c* will also decrease. This factor would tend to amplify the results predicted above.

Within the limits of its assumptions, this model provides a useful tool for considering the potential impacts of disposal costs on the jockey's decision process. These impacts should be carefully considered before any public policy initiative. The social costs of improper disposal and of resource recovery value which also must be incorporated in any policy evaluation

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

are not considered in this model.

The purpose of the following two sections will be to consider the current state of the scrap tire collection market by analyzing scrap tire collection and transportation costs. Our survey and interviews indicate that in many cases the market is in the c_1 position where it is cost effective to send a large number of unsuitable casings to retreaders. However, it is not clear that this is technically avoidable. Further, it seems that in many cases the cost of inspection and transportation is just too high and that it is simply easier to dispose of all scrap tires in a situation comparable to c_2. While in still others, it is too costly to dispose of tires in an environmentally sound manner. In the next section, an analysis of scrap tire collection costs illustrates the potential benefits of illegal disposal to the tire disposer. The difficulty in applying the model presented in this section comes in determining the disposal costs actually being paid by the disposer. In many cases this is less than the legally established disposal fee (202, 236, 240, 242, 244).

COSTS OF SCRAP TIRE COLLECTION AND DISPOSAL

Costs of scrap tire collection and disposal vary significantly from one location to another. However, typical ranges have been identified and can be used to examine the economic incentives for those handling scrap tires. This analysis will be based on the simple case of a jockey collecting discarded tires, selling used tires and retreadable casings, and disposing of the scrap tires. The term disposal will be used in reference to all disposal and resource/energy recovery options.

The variety of options listed above show the difficulty of establishing specific costs for tire disposal. In a few instances, where scrap tires are used for energy generation or rubber reclaim, they may have a positive value. However, the scrap tire disposer more commonly pays all transportation and handling costs in addition to any disposal fees. Indications are that the transportation costs and disposal fees total $0.25 to $0.45 per tire for adequate legal disposal, in most areas. If tires are disposed of illegally, it is expected that these costs can be reduced to $0.15 to $0.20 per tire.

The revenues from the sale of used tires and retreadable casings also fluctuate depending on the type and condition of the tire and other market factors. Five to fifteen dollars is a reasonable resale value for a used tire; the value of a retreadable casing is roughly $2 to $3.

Given these approximate costs, it is possible to estimate anticipated revenues per tire collected. The market studies indicate that 5 to 10 percent of the discarded tires have sufficient tread to be sold as used tires, while 15 to 35 percent of the discarded tires can be sold as retreadable casings (some of which will later be rejected by the retreaders).

In Table 12, these estimates are used to calculate the lower bound, upper bound and expected revenues for a jockey utilizing either legal or illegal disposal of unsalable casings. Assuming that one man can process 100 tires in an eight hour day (at $10.00 per hour, including all expenses), an estimated cost to the jockey would be $0.80 per tire.

Under these assumptions, the lower bound revenues are less than costs, and the work is unprofitable. We assume that these tires are not being collected by anyone because no one can afford to do so. The average jockey, on the other hand, can still make a profit given these cost assumptions. Should this jockey choose to risk illegal disposal, he can expect a 20 percent increase in profits.

The upper bound case illustrates that there is the potential to make significant profits in some situations. These will be the large brokers who have a guaranteed volume and can offer users of scrap tires a fixed supply. One of the most critical factors in this analysis is the sensitivity of the scrap tire market to the cost of disposal.

During this study the experience of three communities which had imposed disposal charges on scrap tires was evaluated. In all cases the community facilities were receiving only a small percentage of the scrap tires generated in the community. Because of public health hazards from mosquitoes breeding in scrap tires abandoned near homes, the La Crosse, Wisconsin disposal charge was modified to exempt individuals disposing of less than four tires. This modification resulted in a sharp increase in the number of residential disposers delivering tires to the community facility (264).

The Metropolitan Service District (MSD) of Portland, Oregon attempted to regulate scrap tire flows within the District. All haulers, landfillers, and shredders were to be bonded and licensed and receipts were to be filed for each transfer of scrap tires. MSD was responsible for reconciling discrepancies. Even with this rigorous accounting system, the MSD could only account for a little over half of the scrap tires anticipated (249). Because the cost of enforcement was so high, the MSD has abandoned the accounting program and has implemented a disposal fee program with fees of $0.25 for passenger tires. One Portland area retreader interviewed indicated that although he was willing to live with the disposal system for the time being, there are other (unnamed) options available to him should MSD raise the disposal fee (245).

In Anne Arundel County, Maryland a disposal fee of $15.00 per ton is charged for scrap tires delivered to the county landfill, where they are shredded before disposal. The county handles only about 4,000 tires per month of the estimated 30,000 generated within its jurisdiction. While officials were not certain where the remaining 26,000 tires per month were going, a substantial number appear to be handled by a private facility, which charges significantly less and which simply buries the tires whole (240, 241).

The experience in these communities clearly illustrates the adverse impacts which can result from the imposition of a local disposal fee. It

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 12. JOCKEY REVENUES AND COSTS

Lower Bound on Jockey's Revenues

	Percent	Price	Revenues Per Tire
Sold Used	5	$5.00	$0.25
Sold for Retreading	15	$2.00	$0.30
Disposed	80	-$0.45 (legal)	-$0.36 (legal)
		-$0.20 (illegal)	-$0.10 (illegal)

Lower bound net revenues with legal disposal: $0.19 per tire.
Lower bound net revenues with illegal disposal: $0.39 per tire.

Upper Bound on Jockey's Revenues

	Percent	Price	Revenues Per Tire
Sold Used	15	$15.00	$2.25
Sold for Retreading	35	$ 3.00	$1.05
Disposed	55	-$ 0.25 (legal)	-$0.14 (legal)
		-$ 0.15 (illegal)	-$0.08 (illegal)

Upper bound net revenues with legal disposal: $3.11.
Upper bound net revenues with illegal disposal: $3.17.

Average Jockey Revenues

	Percent	Price	Revenues Per Tire
Sold Used	10	$10.00	$1.00
Sold for Retreading	25	$ 2.50	$0.63
Disposed	65	-$ 0.35 (legal)	-$0.22 (legal)
		-$ 0.17 (illegal)	-$0.11 (illegal)

Average net revenues with legal disposal: $1.35.
Average net revenues with illegal disposal: $1.43.

EPA-287 (Cin.)
(4-76)

is difficult, if not impossible, to regulate the transfer of scrap casings to enforce manditory disposal practices.

TRANSPORTATION COSTS FOR WHOLE AND SHREDDED SCRAP TIRES

Transportation costs for scrap tires are a significant factor in determining the cost-effective operating radius for the recovery and reuse technologies. A number of the technologies reviewed in Section 4 depend on the ability to collect tires from a distance of several hundred miles. An analysis of the feasibility of these approaches requires an understanding of truck and railroad shipping costs.

Estimates of transportation costs have been developed based on the assumptions presented in Figure 12. Trucking companies, and also railroad operators, have minimum weight charges which are an incentive to ship full container loads. Under such circumstances, the shipment of whole tires by truck or rail, and shredded tires by rail, is limited by the volume of the container. Only in the case of the shipment of shredded tires by truck does a legal weight limitation prevent the shipment of a full load, i.e., a load in which all available volume is used.

The Interstate Commerce Commission is responsible for the regulation of both trucking and railroad commodity carriers. In general, the agency does not prescribe maximum tariffs, but rather approves those tariffs filed by each carrier when a rate increase or authority to carry a new commodity is requested. All tariffs which appear to bear some relation to the carrier's operating costs are approved. Lately rate requests have been frequent because of the rising cost of fuel, which necessitates a fuel surcharge.

Tariffs are filed in conformance with the National Motor Freight Classification for trucking, and the Uniform Freight Classification for railroads. These define specific commodity cateogries; for example, 'used whole pneumatic tires, suitable for reclamation purposes only', or 'shredded scrap rubber, baled and compressed' are the two cateogries used here to determine transportation costs. The tariffs are quoted per hundred weight, with a fuel surcharge added to the total cost.

There are two principal conclusions from this analysis:

- It is significantly less expensive to ship a ton of shredded tires than a ton of whole tires.
- Although rail is a less expensive means of shipment at all distances, it is probably most effectively utilized at distances beyond 500 miles.

Trucking costs per ton mile for typical distances are shown in Table 13. These per mile costs decline rapidly up to 100 miles, at which point they stabilize and decline only very slightly thereafter.*

---

*The correlation coefficient for this data, based on a linear regression, is -0.6107656 for whole tires, and -0.5332378 for shredded tires. Both coefficients are valid to a 99 percent degree of certainty.

BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTION HERE

The prices quoted are September 1979 rates based on tariffs filed with the Interstate Commerce Commission. These rates were obtained directly from the shippers and generally were quoted as $/hundredweight, plus a fuel surcharge expressed as a percentage of the base cost. This surcharge changes frequently.

Whole passenger tires are assumed to have a volume of three (3) cubic feet. Shredded passenger tire volume is one (1) cubic foot, representing a two-thirds volume reduction.

The weight of these tires is 22 pounds each.

The relevant dimensions of the transport containers are:

	Inside Length feet	Volume, cubic ft.	Commodity Weight Limit pounds
truck trailer, box or open topped	45	3500	44,000
railroad box car I	40	3900	120,000
railroad box car II	50.5	4935	110,000

The gross weight limitation for a tractor-trailer combination is 68,000 pounds for single-axle tractors, and 74,000 pounds for double-axle trailers. The lower commodity weight limit for the longer railroad boxcar is a result of the distribution of weight along the axles.

Combining the above information on container dimensions with the estimates of whole and shredded tire volume results in the following estimates of the theoretical maximum commodity weight for each container:

Whole Tires	Weight (pounds)	
Truck trailer	25,700	
Railroad box car I	28,600	Volume--limited
Railroad box car II	36,190	
Shredded Tires		
Truck trailer	44,000	Weight--limited
Railroad box car I	85,800	Volume--limited
Railroad box car II	108,750	

Mileages were derived from the 1979 Commercial Atlas and Marketing Guide, Rand McNally & Company.

Figure 12. Assumptions for the transportation cost analysis.

BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

EPA-287 (Cin.)
(4-76)

Figure 12
(continued)

The following railroads contributed to this analysis:

- Conrail
- Illinois Central Gulf
- Southern Pacific
- Burlington Northern
- Union Pacific

Trucking costs were derived from the following companies:

- Merrill Transport
- Lopez Trucking
- B&B Trucking
- B&E Transportation
- Beacon Fast Freight
- Arrow Transportation
- Calore Cook Transportation
- Fall River & New Bedford Express
- Froehlich Transportation
- Graf Brothers Express
- Consolidated Freightways
- B.N. Corkum Transportation
- Dorn's Transportation
- Hercules Trucking
- Interstate System
- Roadway Express
- Dohrn Transfer

Based on the mileage and $/ton-mile data, linear regressions were performed.

Truck and rail shipping costs for typical distances are shown in Tables 13 and 14 respectively. Regressions performed on these per ton-mile costs indicate that trucking costs decrease rapidly up to a distance of 100 miles (correlation coefficient -0.6107656 at 99 percent degree of certainty) while rail reflects no strong relationship to distances traveled. Based on these calculations, the unweighted average costs of transporting whole and shredded tires are:

Truck	$/Ton Mile
up to 100 miles, whole	.40
up to 100 miles, shredded	.25
above 100 miles, whole	.13
above 100 miles, shredded	.10
Rail	
whole	.06 - .07
shredded	.04 - .06

The assumptions for these estimates are detailed in Appendix A.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 13. TRUCK TRANSPORTATION COSTS FOR SHIPMENT OF TIRES (SEPTEMBER 1979)

		Whole Tires		Shredded Tires	
	Mileage	Travel Cost	$/ Ton-Mile	Travel Cost	$/ Ton-Mile
Boston-Concord	73	$367.92	.3938	$332.44	.2070
Boston-Providence	45	216.09	.3752	289.08	.2920
		239.15	.4152	303.53	.3066
		239.15	.4152	293.90	.2969
		251.42	.4365	251.42	.2540
		242.21	.4205	308.35	.3115
Boston-Portland	115	203.49	.1382	235.62	.0931
		312.73	.2125	312.73	.1236
		264.99	.1800	264.99	.1047
Boston-New Haven	158	358.72	.1774	438.44	.1261
		334.19	.1652	423.98	.1220
		364.85	.1804	462.53	.1331
		361.79	.1789	452.89	.1303
		343.39	.1700	438.44	.1261
Boston-New York	230	512.02	.1739	616.70	.1219
		502.82	.1708	616.70	.1219
		502.82	.1708	616.70	.1219
		315.36	.1071	315.36	.0623
Boston-Buffalo	498	517.39	.0812	517.39	.0472
		672.77	.1055	1108.14	.1011
Boston-Cleveland	624	1066.97	.1336	1315.31	.0953
		947.39	.1186	1315.31	.0958
Boston-Chicago	975	955.89	.0766	1642.94	.0766
Boston-Kansas City	1426	1426.73	.0782	2452.19	.0782

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 14. RAIL TRANSPORTATION COSTS FOR SHIPMENT OF TIRES

		Whole Tires*		Shredded Tires	
	Mileage	Total Cost	$/Ton-Mile	Total Cost	$/Ton-Mile
Phoenix-Los Angeles	425	$ 927.36[1]	.1206	$2517.09	.1091
Boston-Buffalo	498	526.30[1]	.0584	1269.78	.0470
Boston-Cleveland	624	666.02[2]	.0590	1606.89	.0474
Chicago-Vicksburg	759	672.75[3]	.0489	1460.81	.0335
Phoenix-Vicksburg	1445	1931.31[4]	.0739	3494.70	.0445
Seattle-Chicago	2141	2142.45[4]	.0553	3876.76	.0334
Los Angeles-Salt Lake City	775	1428.30	.1018	3876.76	.0921
Los Angeles-Butte	1208	1929.24	.0883	5236.44	.0799

*The estimates for whole tires are based on the minimum-cost ($/ton-mile) container, or a 50' 6" boxcar, not a 40' boxcar.

[1] 45,000 pound minimum, and actual carry of 36,190 pounds.

[2] 45,000 lb. minimum charge, and actual carry of 36,190 pounds.

[3] 50,000 pound minimum, and actual carry of 36,190 pounds.

[4] 60,000 pound minimum, and actual carry of 36,190 pounds.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
5/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TIRE INDUSTRY STRUCTURE

The tire industry in this country is an oligopoly. Indeed, it is (along with steel, oil, chemicals, aluminum and automobiles) one of the classic examples of oligopoly listed in standard texts in industry organization.* Table 15 shows that the top five U.S. manufacturers and their subsidiaries control over 75 percent of the total and passenger tire production capacity. More important from the point of view of this study is the nature of the oligopoly; the tire industry's major source of barriers to entry is its product differentiation, linked to dealerships and extensive advertising.

This oligopolistic market structure with its emphasis on product differentiation has several implications for optimal tire disposal and reuse. The large tire manufacturers engage in the retreading as well as in the production of new tires. Our case studies suggest that these large manufacturers control an increasing portion of the retreading market. Given this fact, it is of some interest to consider whether these oligopolistic firms have the right incentives to produce an optimal mix of new versus retreaded tires. There are large cross-elasticities of demand for the two tires and there seems to be at least some potential for a market distortion.

This problem of a non-competitive firm's behavior in the reuse market is not a new one. The issue first came up in a survey way in an anti-trust case in 1945, U.S. vs. Alcoa. In this case Alcoa was charged with monopolizing the aluminum market; the case turned on the court's treatment of the market definition--in particular, whether secondary (i.e., reused) aluminum produced from Alcoa's virgin aluminum was in some sense under Alcoa's control. Judge Learned Hand argued in this case, "Alcoa always knew that the future supply of ingot would be made up in part of what it produced at the time, and, if it was as far-sighted as it proclaims itself, that consideration must have had its share in determining how much to produce."** In the tire case the control is even more substantial since the major companies control not only the virgin market, but an increasing share of the retread market.

Given that the large tire manufacturers exhibit substantial control over both new and retread tire markets, do they provide the socially optimal mix? The answer, it turns out, depends on demand elasticities for the two types of tires. Suppose that *at some relative prices*, retreaded and new tires were viewed as perfect stustitutes. In this case, there would be no difference in demand elasticities for the two tire types and as long as our firms are profit-maximizers, the tire mix will be chosen so as to maximize profits. *If all other prices are correct*, the mix between retreads and new tires will be optimal and the market structure is non-distorting.

---

*For example, F.M. Scherer, *Industrial Market Structure and Economic Performance*, Chicago: Rand McNally, 1970; or L. Weiss, *Case Studies in American Industry*, New York: Wiley & Sons, 1971.

***U.S. vs. Alcoa*, 148 F.20416 (2nd Cir., 1945)

TABLE 15. PERCENTAGES OF 1979 PRODUCTION CAPACITY BY COMPANY

Manufacturer	Percent of Total Tire Production Capacity	Percent of Passenger Tire Production Capacity
Goodyear	24%	25%
Firestone	22%	22%
Uniroyal	12%	13%
General	9%	9%
B. F. Goodrich	9%	9%
Other	24%	22%

9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

If, on the other hand, new and retreaded tires are not perfect substitutes, (at a price), so that demand elasticities differ, the product mix will not generally be optimal. The standard analysis of this problem is due to Eli Clemens.* Suppose we have a multiproduct firm which produces products which are related to each other but have different demand elasticities. Suppose, as in the tire industry, the firm has some market power. We would expect, in this case, that firms would charge a higher profit margin in the inelastic market; or, in other words, the inelastic product would be undersuppled relative to the elastic product. In this case the product mix is distorted by the market structure, although the distortion will be mitigated somewhat if fringe firms can enter and compete away the high margin product.

In sum, one problem in the tire industry is that new and retreaded tires are not perfect substitutes, exhibiting different demand elasticities; since the markets of the large firms are somewhat protected, the mix of new and retreaded tires produced by these firms may be incorrect.

There is an additional problem created by the market structure of the tire industry. As indicated earlier, the major source of the barriers in the industry is product differentiation. Major firms in the industry compete via dealerships and brand proliferation. This has been recognized for some time. In 1964 the Federal Trade Commission pressed the industry to adopt a uniform grading system, to reduce size proliferation.** The tendency of oligopolistic firms, producing consumers' goods, to produce an excessive number of brands or product varieties as a way to compete is well known. Recently, in looking at the breakfast cereal industry, Schmalensee+ argued that firms in these kinds of industries use brand proliferation as a strategic weapon against a new entry into an industry. Further size and brand proliferation reduce the rate of retreading. Thus, the new tire market structure creates problems primarily in terms of the number of tires retreaded; that is, there are good reasons that the industry may retread too few tires.

The number of OE tire sizes for 1970, 1978, and 1979 are summarized in Table 16. As these figures indicate, the number of sizes available has increased by 25 percent over the nine year period. Finney (160) in reviewing the questions of tire sizes concluded that the total number of tire sizes could be cut in half by a reasonable standardization scheme without compromising vehicle performance. It has been suggested that the auto industries marketing approach of providing unique options has been one driving force behind variations in tire sizes.

There is some evidence of brand proliferation in the tire industry. The Modern Tire Dealer industry analysis lists twenty brands, each brand

---

*Clemens, "Price Discrimination and the Multiple Product Firm," Review of Economic Studies, 1951.

**Scherer, op. cit., p. 189.

+R. Schmalensee, "Entry Deterrence in the Ready to Eat Breakfast Cereal Industry," Bell Journal, Autumn, 1978.

TABLE 16

ORIGINAL EQUIPMENT TIRE SIZE

Year	Standard Equipment	Optional Equipment	Total
1970	34	33	40
1978	42	35	49
1979	30	44	50

controlling at least 1.0 percent of the passenger replacement tire market. Of these, nine are so-called house brands. In 1978 these private brands accounted for approximately 35 percent of the replacement tire sales.

As an oligopoly the tire industry can be expected to demonstrate both size and brand proliferation. Similarly, the industry incentive structure would not support an aggressive retreading program. While there is some indication that the industry has in fact fallen into these patterns, the evidence is by no means overwhelming. However, the nature of the tire industry structure should be carefully considered prior to initiation of any public policy.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

SECTION 4

TECHNOLOGIES

All of the technologies for disposing of scrap tires, whether proven, emerging, or speculative, can be classified into two categories: those using whole tires, and those using tires on which some level of size reduction has been carried out. For the applications involving whole tires, the tire input costs are: the cost of tire carcasses and the cost of transporting the tires from where they are generated to where they can be utilized. Size reduction is an additional input cost to the technology in use. We will first examine retreading, the primary use of whole tires and then review the types of size reduction and pursue the various production processes which utilize tire fragments of various types and sizes.

Size reduction techniques can be categorized as mechanical, cryogenic, chemical, or microbiological. Mechanical size reduction involves machines which do one or more of the following to a tire: punch, slice, tear, or pulverize. Cryogenic size reduction involves exposure of tires to liquid nitrogen until they become brittle, at which time they are subjected to one of the mechanical techniques, with less mechanical energy required to break them up. Chemical and microbiological techniques are rare and generally not economically proven. It should be pointed out that the widespread use of steel-belted radials has tended to raise operating costs and/or lower feasible throughput for most, if not all, size reduction techniques.

RETREADING

It takes approximately 30 percent of energy and materials to retread a casing as to make an equivalent new tire. In general, retreaded tires provide about 80 percent of the mileage of a new tire. Thus, retreading a casing once results in a 30 percent savings in energy and materials per mile traveled.

There are two major types of retreading. The first two steps in both processes are the inspection of the casing for retreadability and the removal of the old tread by buffing. In the conventional "hot" process, the next step involves applying new rubber to the buffed casing and placing it into a tread-forming mold for up to an hour at high pressure and temperature. The relatively new "cold" processes involve the bonding of a precured tread to the casing. This bonding can be achieved at much lower pressures and temperatures than the conventional retreading techniques, although more time is required.

To be acceptable for retreading, a casing must be sound with no major punctures, splits or cracks. Side wall damage generally results from poor

BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

tire maintenance, especially under-inflation and impacts with curbs. On the average, tires on commercial vehicles are maintained significantly better than passenger tires and this helps explain the difference in overall retreadability rates between passenger (18 percent) and truck (30 percent) tires.

At the present time about 10 percent of all tires are not retreaded because they represent obsolete styles or sizes for which there is no market. As the percentage of passenger radials increases, the retreading industry has been faced with a double challenge. The rejection rate of passenger radial casings is very high and it is more costly to retread the few acceptable casings. Passenger radials are more difficult to retread than bias tires because the tolerances for fitting "hot" process molds are much tighter. Tolerance for radials is ± 1/4 inch difference between the mold and actual tire size, for both the bead diameter and the tread width. This compares to a tolerance of 1/2 to 7/8 inch for bias tires and 1/4 to 1/2 inch for bias-belted tires.

The National Highway Transportation Safety Administration (NHTSA) has developed regulations specifying minimum standards for retreadable casings. A low percentage of radial casings meet NHTSA requirements. First, radial side walls have tended to be weaker than those of bias tires, making them more vulnerable to damage resulting from the under-inflation and collisions with curbs. Secondly, because radials have higher first tread mileage, there is a significantly longer period of time during which casing damage can occur. Finally, early U.S. radials were poorly constructed and prone to belt edge separation, a pulling away of the belting fabric from the rest of the casing. This condition makes the casing unretreadable.

Truck tires, on the other hand. are more retreadable. They have a rejection rate of approximately 70 percent and many can be retreaded two or three times. Steel-belted radial truck tires are particularly well adapted to retreading because of superior construction. Because new truck tires are so expensive, it is cost-effective for trucking companies to maintain their tires and retread as many tires as possible. The need for a well-constructed steel-belted radial has not been as strong in the passenger car market and only now are we beginning to see a well constructed domestic passenger car radial. It is widely agreed that lack of suitable casings is the primary limiting factor in the retreading business (202, 243).

As discussed in Section 3, if retreaders are to maintain current volumes, retreading of radials must increase significantly. Such increases will clearly require major capital expenditures for equipment and high overhead rates to cover the cost of disposing of a significantly higher percentage of non-retreadable casings.

The two major waste streams from a retread operation are the rejected tires and the rubber buffings. In most cases the rejected tires are hauled off by an independent broker or jockey who often reinspects the tires and sells them to less selective retreaders. The remaining tires are either dumped in a landfill or dumped illegally. The rubber buffings are sold to rubber reclaimers.

EPA-287 (Cin.)
(4-76)

SIZE REDUCTION PROCESSES

Because they are not entirely rigid, it is difficult to slice or pulverize tires. Power for tire shredders varies from 30 to 200 horsepower. Whole truck tires are not handled well by most shredders and should be sliced in half before they are fed into the shredder, while large construction tires cannot be handled at all. It should be noted that manufacturers tend to quote piece sizes and processing rates based on ideal design conditions, which are therefore highly optimistic, making comparisons difficult. Realistic operating costs, piece sizes, and processing rates can only be obtained from businesses actually operating the machines on a daily basis.

One of the simplest and most effective designs in the field is embodied in machines marketed by Shred-Pax, Inc. and Mitts and Merrill, which use hooks on two slow oppositely rotating shafts to simply pull the tires into pieces. These units come in three sizes and require the following accessories for smooth operation: small amounts of water inflow to lubricate the tires, a vertical conveyor to feed tires, a hopper (vertical design most effective), a container to receive shredded product, and a horizontal conveyor to move the product from below the shredder to the storage container. This design has been successfully applied to both stationary and mobile operations whose effective costs (1978 dollars inflated from 1975 estimates) are listed in Table 17.

A smaller and cheaper machine is the Rawls Tire Chopper produced by the National Standard Company. This machine sells for about $32,000 as a complete trailer-mounted unit and several of them are operating around the country. Data for this machine is available in Table 18.

Montgomery Industries of Jacksonville, Florida, has developed a two-stage shredding process which first produces 2 to 6 inch pieces and then 1 to 2 inch particles with almost all metal separated. The first stage operates at 400 horsepower, but extremely low costs of $40,000 capital per unit and $4 per ton operating are claimed. This system is engineered for a permanent installation only. Hourly throughput for the system is claimed to be 2,000 passenger car tires and 600 truck tires.

A number of shredders that can handle whole tires have been developed and are in use in Europe (the design used in the Shred-Pax models was pioneered in Europe). Other American machines adaptable to tire shredding are made by Tire-Gator, Inc. of Houston, Saturn Manufacturing of Portland, Oregon (marketing the Tire-Gon machine), Holman Industries of Oakdale, California and doubtless many others. Cost information for many of these machines is presented in Table 19.

Very recently, the Pacific Energy Recovery Corporation has developed "primary" and "secondary" shredders which are in use in Portland, Oregon and possibly elsewhere. In addition, some companies have developed their own shredding devices, typically tailor-made for their operations and not produced for sale to anyone else. An example of this situation would be the Metropolitan Disposal Company of Portland, Oregon and U.S. Rubber Reclaim of

TABLE 17

STATIONARY MECHANICAL SHREDDING (240, 241)

Basic Operating Equipment

Shredder	$53,974
Electrical Hookup	1,935
Conveyor	7,224
Miscellaneous	1,367
	$64,500

Capacity: 400 tires/hour x 8 hrs/day x 250 days/year = 800,000 tires/yr

Calculation based on: ≈ 350,000/year.

Operating Level: ~50,000 tires/year

Hourly Costs:

Depreciation	$ 11.10
Maintenance, parts	2.58
Labor (2@ $5.00)	12.90
Electricity	1.94
Hauling	10.32
	$ 38.84 or 10¢/tire

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 17
(continued)

MOBILE SHREDDING OPERATION (242)

Revised Capital Investment and Operating Costs

Basic Operating Equipment: $76,000*

Capabity: 20 lbs/tire x 350 tires/hour x 8 hours/day x 250 days/year = 14,000,000 lbs/year

(This is a theoretical maximum--they seldom handle this much.)

Annual Costs (Operating & Depreciation)

Amortization**	$7.60/hour
Maintenance	$2.50/hour
Fees & Insurance	$2.00/hour
Fuel	$4.00/hour
Operator	$7.00/hour
Helper	$5.00/hour
Extra Truck	$5.00/hour
	$33.10/hour ≃10¢/tire

*Special case, normally would be ~110,000.

**Special case, could be $11.00/hour or more.

TABLE 18

ESTIMATED CAPITAL INVESTMENT AND OPERATING COSTS FOR CRYOGENIC GRINDING OF TIRES (AIR PRODUCTS)

Basic Operating Equipment = $450,000*

Capacity: 6,000 lbs/hr x 16 hrs/day x 250 days/yr =
24,000,000 lbs/yr ≃ 1,250,000 tires/yr or
11,250,000 kg/yr

	$/year	¢/KG
Depreciation	$45,000*	0.4
Interest	$22,500*	0.2
Power	$29,500**	0.262
Labor	$84,500**	0.751
Maintenance/Material	$45,000*	0.4
Liquid Nitrogen	$450,000**	4.0
	$676,500	6.013

* As per Michael Kazarnowicz (239)

** Revised by USR&E.

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 19. A SAMPLE OF BUSINESSES AND OTHER OPERATIONS UTILIZING SIZE REDUCTION

COMPANY	LOCATION	PROCESS	PRODUCT	CAPACITY (# tires)	CAPITAL COSTS	OPERATING COSTS (year)	REFERENCES
Air Products & Chemicals, Inc.	Pilot plant in Allentown, PA; company is trying to sell process equipment to others	Cryogenic treatment followed by grinding; CRYOGRIND optional	Subject to specifications 200-mesh to ¼" particles rubber-plastic products	1,250,000/year	$450,000 - $600,000	$675,000-$1,000,000	Interview with Michael Kasarnowicz (239)
Alternative Energy Co.	Attempting to establish system in California	Guhl's Tire Scrapper	2"-10" pieces volume reduction for transportation purposes	~300,000/year per proposed operation	Not Available	$110,000	Interview with Jack Cunningham (201, 229)
Anne Arundel County	Millersville, MD	Shredpax AZ-45T	2"-8" pieces currently landfilled	~350,000/year (not operating anywhere close to this level)	$75,000 - $100,000	$29,000 - $40,000	Interviews with Joe Schiren and Parker Andrews (240, 241)
Big "O" Tire Company	Oakland, CA	Rawls Tire Chopper (run through twice)	1"-4" chips burned at sawmills	~300,000/year	$30,000 - $50,000	Not Available	Interview with Bill Thomas (230)
Ecological Energy Corp.	Concord, NH (not yet in operation)	Mechanical shred/ grind (unspecified machinery)	Subject to specifications 60-mesh or finer to ¼" particles-mostly for fuel	24,000,000/year	$1,000,000-$1,125,000	Not Available	Interview with Murry Baker (225, 254)
Environmental Shredder Systems (Garner Equipment)	Mobile operation-based in Washington, DC	Shredpax AZ-45T mounted with generator on truckbed	2"-8" pieces currently landfilled but under consideration for composting, oyster cultch	600,000/year (does not operate anywhere near this level)	$73,000 ($110,000 current)	$60,000 ($67,800 current)	Interview with Howard Beezer (242)
Genstar	Operation planned for Phoenix, AZ	Cryogenic treatment followed by grinding	Crumb rubber for asphalt, paints, other specialized uses	1,200,000/year	Not Available	Not Available	Interviews with Bill Thompson (211)
Metropolitan Disposal Co.	Portland, OR	All mechanical shredders: (a) Tire Hawg (b) Tire Hawg with PERC secondary (c) PERC primary	8"-10" chunks } for fuel 2" chips } for fuel 2" chips } for fuel	1,200,000/yr claimed; ~750,000 /yr more likely 1,200,000/yr claimed; ~750,000 /yr more likely 1,000,000-1,320,000/yr	$60,000-$100,000 Not Available $170,000	Not Available Not Available Not Available	Interviews with Jim Cozzetto and Dick Kuhnau (244, 227)

Vicksburg, Mississippi. The capital and operating costs are even more vague for these applications.

There have been a number of proposals and some demonstrations of cryogenic treatment of tires prior to shredding. A mobile version of this process has been demonstrated by Professor Norman Braton (63) and a patent for a mobile cryogenic shredder is apparently held by Mr. Vernon Richardson of Houston (239).

Air Products and Chemicals, Inc. of Allentown, Pennsylvania is attempting to market a cryogenic tire shredding process. Their process involves coarsely shredding the tires (to avoid entrapment and waste of liquid nitrogen inside the tires), and feeding the shred through a freezing tunnel, in which it is continuously exposed to LIN and embrittled. As the embrittled tires are ground, heat is generated which helps to maintain a suitable ambient air temperature in the chamber containing the grinding equipment, allowing the use of equipment made of ordinary carbon-steel. Fiber and steel can be almost entirely separated. The steel is clean enough to be sold as scrap, but uses for the fiber are not yet clear.

The rubber can be ground to a wide variety of particle sizes depending on the intended use, although the quoted costs are based on a size of 1/4 to 1/2 inch. Sizes down to 60-mesh or finer can be obtained by adding additional machinery. A representative of Air Products declined to quote specific figures on total energy use for their system, but did say that "no more than" one half pound of LIN is required per pound of tires processed. Reference was made to a study which showed that clean finely ground rubber particles could be produced through this process for one third less energy per pound than new rubber. However, ground rubber may not be entirely substitutable for new rubber. Estimated direct costs for the Air Products process are presented in Table 19 -- based on Air Products' pilot plant operation experience and some rough estimates by their engineers concerning scale-up. They suggest that prospective customers double the costs Air Products has calculated to obtain a ballpark figure for the total system cost. Air Products assumes a zero cost for the tire input--since considerable handling would be required to assemble 1,250,000 tires per year in one location, any company using the proposed system would almost certainly have to charge a suitable fee to cover these costs.*

---

*Since the drafting of this report, Air Products has informed us that two additional U.S. installations will be on-line by early 1980. Both companies anticipate manufacturing crumb rubber for use in: (1) rubberized asphalt; (2) industrial molded goods; and (3) waterproofings/sealants.

USES OF SHREDDED TIRES

Shredding for Landfill Life Extension and Miscellaneous Uses

A large number of landfills around the country try to shred tires before burying them, thereby substantially reducing the volume consumed and eliminating the problem of tires surfacing and having to be buried. In general, though, most landfills do not segregate the shredded tires in separate cells that could be easily "mined" in the future. A very few of the larger landfills have their own fixed shredding equipment.

Anne Arundel County, Maryland has a tire disposal fee of $15 per ton, and tires from all three landfills in the system are transferred to the Millersville Landfill for shredding and disposal (240). The installation consists of a Kleco shredder indentical to the Shred-Pax AZ-45 in conjunction with a Branick Tire Slicer to halve truck tires prior to shredding.* The county is receiving considerably less than the projected quantity of tires. The county only handles an estimated 50,000 tires per year out of a probable annual generation of 350,000 (241). As a result, the shredding operation consumes a relatively small amount of time and can be handled by personnel normally assigned to other functions at the landfill. There is universal agreement that the reason the county handles only one seventh of all waste tires generated is the existence of less costly alternatives. In the absence of effective penalties, the risk of illegal disposal is worth the savings of the disposal fee.

Many landfills which do not handle enough tires to justify maintaining their own shredding equipment hire companies with portable equipment. Environmental Shredder Systems, Inc. (ESS) is such a firm based in Washington, DC.** The company uses a Shred-Pax AZ-45 shredder with input and output conveyors and a diesel generator that consumes 80 gallons of fuel for every 5,000 to 6,000 tires shredded. ESS has contracts with a number of landfills and a number of the larger tire dealers in the Middle Atlantic region. They normally charge 25¢/automobile tire for onsite shredding ($25/ton), but have bid as low as 16¢/tire (242). The company does not pick over the tires it handles for retreadable casings. Although their coarsely shredded product is presently all landfilled, ESS is investigating two other options: the use of shredded tires as a substitute for wood chips (now selling for $32/ton) in a sewage sludge composting project at the Blue Plains Treatment Plant in Washington, DC and as a substitute oyster clutch in Maryland's oyster fishery. Both possibilities are at an exploratory stage.

Some other companies that operate or have operated mobile shredding equipment include the Tire Shred Company of Graham, North Carolina (using the

---

*Operating costs for this system were presented in the "stationary" portion of Table 17.

**The costs associated with their operation were presented in the "mobile" portion of Table 17.

Rawls Chopper), the Kendall Equipment Company of Wallingford, Connecticut and Blanchard's Tire Shredding in Hillsboro, New Hampshire. As was noted earlier, proposals have been made for mobile cryogenic shredders of tires but as far as we can tell, these are not yet in commercial use anywhere.

A summary of processes, products, and costs for a selection of companies utilizing size reduction is presented as Table 19. A serious difficulty in evaluating the various technologies has been that many of the companies are at such an early stage of operation that they cannot provide accurate and/or complete cost data.

Asphalt-Rubber Applications

The most recent set of experiments with asphalt-rubber compounds began in the city of Phoenix in 1967. Charley McDonald, then city engineer and now retired, utilized reclaimed rubber in combination with asphalt as a binder on chip seal coats, in hopes of prolonging the life of badly distressed asphalt pavements. Since that time, the Federal Highway Administration, the Arizona Department of Transportation (ADOT) and various other state highway departments have been involved in a number of demonstration programs investigating a variety of applications for asphalt-rubber compounds.

In 1968 Sahuaro Petroleum and Asphalt Company of Phoenix became interested in the potential of the process and began work to develop application techniques, appropriate formulations, and special equipment. Although Sahuaro is the major company in this field, they were joined in 1974 by the Arizona Refining Company, also of Phoenix. These two companies remain the only two producers of asphalt-rubber formulations.

When the first formulations were devised, the reaction between the two substances was poorly understood. It is now apparent that the rubber is reacting primarily with the resin portion of the asphalt. These rubber particles are between +16 and -25 mesh, and swell to approximately two times their original size. Combined with hot asphalt, the reaction takes place rather quickly, and allows for immediate use of the material.

Work is under way to develop appropriate test procedures for asphalt-rubber compounds, for "the viscoelastic properties of the hot asphalt-rubber binder differs so greatly from asphalt, that normal asphalt test procedures are of little value in describing its behavior" (45). This has hampered evaluation of the material by testing laboratories and highway departments.

However, the asphalt-rubber compounds developed by Arizona Refining Company and Sahuaro differ markedly from conventional rubberized asphalts, whose properties are essentially those of an asphalt. "...It is postulated that the asphalt is serving to modify the elastic properties of the rubber rather than the rubber serving to modify the...asphalt. This difference from...asphaltic concrete using low percentages of rubber is basic..." (45).

Potential uses for asphalt-rubber are:

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

- chip seal coats (stress-absorbing membrane)
- stress absorbing membrane interlayer
- pond lining
- bridge decks
- joint or crack sealer
- membrane over expansive clays.

There is a great deal of enthusiasm for the material on the part of Sahuaro and Arizona Refining Company, as well as the Arizona Department of Transportation, and there are a number of active FHWA demonstration programs underway in about 25 states. However, these programs typically are only about two years old, with at least five years required for a definitive test of an experimental road material. Therefore, data on field performance are lacking.

6-1/2"

Sahuaro Petroleum and Asphalt Company (233, 235)

Sahuaro is involved in refining and conventional asphalt production; however, about 50 percent of the company's work is asphalt-rubber applications. Involved since 1968, Sahuaro services over 90 percent of current asphalt-rubber markets. They currently have 14 special asphalt-rubber spreader trucks, produced by a wholly-owned subsidiary, Bearcat. Joint-sealing units are produced by another subsidiary, Crafco, and are in turn marketed by Sahuaro.

The Sahuaro mixture is 25 percent rubber by weight. The Sahuaro product is frequently considered an equal alternative to Arizona Refining Company products by government agencies, and the companies frequently compete on jobs.

The asphalt-rubber is prepared as follows: +16 to -25 mesh rubber particles are added to asphalt with continuous mixing at 350 to 400°F. The rubber begins to swell, increasing the volume of the mixture, and increasing the viscosity of the asphalt as light oils are absorbed by the rubber. Kerosene is added at a rate of 5 to 7 percent to reduce viscosity so that the mixture may be placed by a spreader truck.

The original supplier of rubber was the Atlos Rubber Company of Los Angeles, which supplies a primarily synthetic mixture derived from passenger car treads. The rubber is mechanically ground. Sahuaro has diversified to other sources, including Centrex (Findlay, Ohio), Eastern Rubber Reclaimers (Andover, Massachusetts), and several other U.S. and Canadian suppliers. Sahuaro prefers a mechanical grind, because it produces elongated rubber particles, which interlock ideally with the asphalt. Cryogenic rubber particles, on the other hand, are more rounded. Cost for the rubber is currently 6¢ to 15¢ per pound plus freight costs. The company generally stockpiles about one million pounds of rubber at any given time, and is

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

sporadically approached by rubber suppliers. Sahuaro will probably apply 30 million pounds of asphalt-rubber compounds in 1979, representing 7.5 million pounds of rubber (or the equivalent of 350,000 scrap passenger tires).

Sahuaro comprehensively tests a variety of asphalts from local supplers in each state where asphalt-rubber formulations are to be used. This testing assures optimum mixing time and temperature. Sahuaro acts only as a supplier. While this avoids difficulties with local asphalt contractors, it occasionally causes quality control problems. The company has thus far refused to license local suppliers of its product, which has raised costs. However, changes in this policy are considered inevitable.

The crack seal compound produced by the company is called Overflex™. The crack sealing machines produced by Crafco have a 200 gallon capacity, continuous mixing augers, twin hoses, and separate heat sources for the nozzles. These machines retail for about $11,000 and can be used for conventional crack seal compounds. The Overflex,™ also used for pond linings, is packaged in paraffin-lined boxes, which degrade at the mixing temperature. The use of asphalt-rubber for pond linings has not been documented sufficiently to provide a basis for conclusions as to its efficacy.

Sahuaro, while reluctant to discuss specific costs, provides the following equivalencies:

- 6/10 gallon per square yard chip seal coat is equivalent in cost to a 1 to 1-1/4 inch asphalt concrete overlay, but has the durability of a 3 to 4 inch overlay.

- 6/10 gallon per square yard asphalt-rubber interlayer plus 2 inch asphalt concrete overlay has the durability of the 7 inch overlay typically applied to badly distressed roads, but at much lower cost.

The concept of an interlayer is about three years old, and came about specifically in the context of asphalt-rubber compounds: an interlayer is not normally applied in road work. Phillips Petroleum, DuPont, and others are attempting to compete in this market with fabric interlayer technologies.

Arizona Refining Company (233, 234)

A subsidiary of Union Oil Company, Arizona Refining Company has been involved with asphalt-rubber formulations since about 1974. They became involved at the behest of Gene Morris of the Arizona Department of Transportation.

Arizona Refining Company uses U.S. Rubber Reclaim (USRR) in Vicksburg, Mississippi as an exclusive source of rubber. USRR supplies an ambient grind under a long-term contract consisting of a mix of:

- natural rubber scrap, vulcanized

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
FPA-287 (Cin.)
(4-76)

- totally reclaimed rubber from passenger car tire treads, 'devulcanized', primarily synthetic
- truck and bus tires with a high percentage of natural rubber, vulcanized.

The totally reclaimed rubber is about 40 percent of the mixture, according to product specifications and the Arizona Refining Company's mixture comprises more natural rubber than Sahuaro's. In appearance, the Arizona Refining Company's rubber consists of noticeably larger particles.

More significantly, the Arizona Refining formulation, called ARM-R-SHIELD,™ consists of 20 percent rubber by weight. The low viscosity (compared to Sahuaro) allows the formulation to be 'shot' from conventional spreader trucks.

The ground rubber and asphalt cement are continuously mixed at 350-425°F for about 30 minutes. Application temperature is 375-425°F.

The current rate paid for the rubber is about 25¢ per pound, plus freight. To reduce freight costs from Vicksburg, the company has executed a backhaul agreement such that rubber is brought to Arizona in empty refrigerated produce trucks. The special freight rate is about one-half the normal packaged goods rate.

Arizona Refining Company is allowing local contractors to mix their own asphalt-rubber compounds. The rubber is either packaged from Arizona Refining, or directly from U.S. Rubber Reclaiming. In either case, an Arizona Refining supervisor is onsite to assure that asphalt-rubber is produced and applied according to specifications.

Arizona Refining Company supplies for the same uses as does Sahuaro, and in addition is promoting asphalt-rubber open-graded mixes applied above an asphalt-rubber membrane. Arizona Refining states that asphalt-rubber seal coats cost about $1.10 per square yard, as opposed to 60-65¢ for a conventional seal coat. Durability for the asphalt-rubber is assumed to be at least twice that of the conventional substance.

Idaho Transportation Department (ITD) (238)

We viewed a number of road surfaces near the Boise area representing a variety of asphalt-rubber applications, including interlayers, chip seal coats, and joint/crack sealers. ITD has worked primarily with Sahuaro, although Arizona Refining has done some seal coats.

ITD is currently in the second year of two five-year evaluations of asphalt-rubber road surfaces as part of an FHWA demonstration program. Althought the program is incomplete, the results--at the sites we visited--indicate that asphalt-rubber formulations do not have a performance superior to conventional treatments, except when used as a joint/crack sealer.

ITD Joint/Crack Sealer Evaluation

As a joint/crack sealer, asphalt-rubber supplied by Sahuaro (Overflex^{TM}) is far superior to any other material ITD has tested, including some other mixtures with small proportions of rubber. Three different sections of Interstate 80 North were test sites.

"Subsequent evaluations of the test sections to date show very good performance with the cracks well-filled. Good adhesion of the sealer was also noted. No cracking is evident." (152) In this case the Sahuaro Overflex^{TM}) was compared with Flo-mix, a compound provided by U.S. Rubber Reclaiming in Buffalo, New York. More recent comparisons verify that Overflex^{TM} provides better performance. Idaho has some rubber joint sealers which have been in place five or six years, whereas conventional sealers rarely last even a year.

Costs are as follows:

o	Flo-mix sealer mixed in Boise	$.61 FOB Boise
o	Overflex M.S. sealer mixed in Boise	$.79 FOB Boise
o	Overflex M.S. sealer premixed	$2.33 delivered Boise.

The additional cost of the Overflex^{TM} relative to Flo-mix is offset by its superior performance. The principal advantage of the premixed sealer is that it can be used in locations where heated asphalt is not available for mixing with rubber. Overflex^{TM} is not recommended for cracks narrower than one-half inch.

ITD Seal Coat Evaluation

ITD evaluated a Sahuaro seal coat on a section of future Interstate 80 North near Caldwell, Idaho which showed extremely bad alligator cracking. It was the opinion of ITD that, because of the severe distress, the road would not provide acceptable service without remedial action.

Application in late 1977 was .64 gallons per square yard. Pictures were taken of all evaluation sections before and after construction. "Many of the pre-existing cracks can be seen again after a year, which is similar to the performance expected of an ordinary seal coat." (153) Cost for the asphalt-rubber alone was $.866 per square yard, or $1.35 per gallon, almost double the cost of conventional seal coats. Furthermore, asphalt-rubber seal coats have not been successful to date in keeping moisture from undersurfaces.

ITD Stress Absorbing Membrane Interlayers Evaluation

ITD evaluated a number of asphalt-rubber stress absorbing membrane interlayers (SAMI) under asphalt concrete for demonstration/experimental purposes. At Cleft Sebree on I-80N, .60 gallon per square yard asphalt-rubber was applied in 1977 with covercoat under .20 foot of asphalt concrete.

EPA-287 (Cin.)
(4-76)

At Nampa-Meridian, .60 gallon per square yard asphalt-rubber was applied in the same year under a similar overlay. Asphalt-rubber costs were $.77 per square yard ($1.28/gallon) and $.82 per square yard ($1.36/gallon) respectively.

As of December 1978--one year after application of both interlayers--very little incipient crack reflection was noted. However, by the time of our February 1979 visit, transverse cracks were reflected at regular intervals of about 50 feet. It was the opinion of the ITD representative that these are cracks from the old underlying surface, and that therefore the interlayer has performed unsuccessfully. This is based on the rule of thumb (common among highway departments) that each 1/10 foot of overlay is worth a year in preventing cracks from reflecting.

On Interstate 80 North near Burley, ITD applied .59 gallons/square yard of asphalt-rubber under .15 inch plantmix overlay. The granulated rubber alone was $1.54 per square yard. The asphalt-rubber together was approximately $2.72 per square yard or $4.61 per gallon. This extremely high cost has not been offset by the performance of the material, as transverse cracking has appeared in the second winter, 14 months after initiation of the project.

Arizona Department of Transportation (ADOT) (233)

The State of Arizona has been involved with asphalt-rubber compounds since 1967, and has been the leading force behind research in this area. In addition, based on a number of demonstrations carried out in the state, ADOT is a major proponent of the material.

> "Conclusions from these projects and years of work are clear. The asphalt-rubber membrane when placed as an interlayer (SAMI) will virtually eliminate the reflection of all cracking...* The asphalt-rubber when placed as a seal coat (SAM) will control** reflection of fatigue cracks and is an effective alternate to major overlay or reconstruction." (154)

ADOT has the following asphalt-rubber experimental/demonstration projects:

- 25 sites testing stress absorbing membrane interlayers (SAMI) over flexible pavement, the oldest being seven years.
- 50 to 60 sites testing stress absorbing membrane projects, some as old as 11 years.

---

*Over flexible pavements.

**i.e., Prevent or greatly reduce.

- 5 or 6 sites testing interlayer/overlay configurations over concrete.

The 25 SAMI projects have overlays ranging from 1 to 3 inches.

ADOT officially recommends an asphalt-rubber interlayer whenever the overlay is less than four inches. It is also highly recommended for any new work as a subgrade, and as an interlayer under extensive overlays on expansive clays.

ADOT has performed a major case study which provides some additional insight into the benefits and costs of asphalt-rubber treatments. The test program involved 18 selected roadway test sections, with control sections of conventional overlays.

The program was carried out at Minnetonka-East near Winslow, Arizona on Interstate 40. Temperatures range from zero degrees to 100 °F during the year. Construction was completed as of June 1972, and was reviewed periodically up to publication of a final report in May 1976. Special photographic techniques and an optical grid system were used to determine the extent and type of cracking both before and after the overlay.

The test sections are as shown in Table 20. The performance of these test sections as of December 1975 is shown in Table 21. Five treatments significantly reduced reflective cracking: they are those shown above the dotted line in Table 21. An asphalt-rubber interlayer was one of these treatments; however, it is equally important that four other types of treatment produced significant positive results.

The average installed costs of the 19 test treatments are shown in Table 22. These are derived from project bids, plus manufacturer's literature, and may not be necessarily representative of projects outside the purview of ADOT. Of the five recommended treatments, asphalt-rubber is the second most expensive. After three years of maintenance, the relative costs of these treatments compared to control sections are as shown in Table 23. The recommended treatments relative to each other do not show benefits based on operation and maintenance costs plus construction, but all are clearly superior to the control treatment after three years' experience. The most interesting conclusion is that there are equally cost-effective alternatives to asphalt-rubber in road construction, which show the same benefits in reducing reflective cracking.

National Asphalt Pavement Association

Consumption of asphalt for road paving purposes in 1976 was 29.09 million tons according to NAPA statistics,** broken down as follows

---

*ADOT terminated this research after three years, so additional operating cost experience is not available.

**Conversation with Richard Smith, NAPA, April 10, 1979.

TABLE 20. TEST AND CONTROL SECTION LISTING (103)

Test Section No.	Description
1	Asphalt Rubber Plus Pre-Coated Chips
2	Heater Scarification Plus Petroset
3	Asphalt Rubber Membrane Interlayer--Placed Over AC and Under ACFC
4	Asphalt Rubber Membrane Interlayer--Placed Over AC and Under ACFC
5	Asbestos Fortified AC Mix
6	Two Inches AC, No ACFC
7	Los Angeles Basin 120/150 Penetration Asphalt
8	Los Angeles Basin 40/50 Penetration Asphalt
9	Four Corners 120/150 Penetration Asphalt
10	Los Angeles Basin 200/300 Penetration Asphalt
11	Emulsion Treated Base in Place of AC
12	Petromat Placed Under Overlay
13	Fiberglass Placed Under Overlay
14	Petroset Flush of Overlay Before ACFC Placed
15	Petroset Placed in Cracks
16	Reclamite Placed in Cracks
17	Reclamite Flush of Old AC
18A,B,C	Heater Scarification of Old AC Plus Reclamite Flush, with Varying AC Overlay Thickness
Control Sections	Conventional (Standard) Overlay

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

TABLE 21. TEST SECTION RANKING (103)

Treatment and Test Section (T.S.) Designation		Percent of Reflective Cracking Appearing by 1975
1-¼" AC Overlay and ½" ACFC		
Heater Scarification with Petroset	T.S. No. 2	3
Asphalt Rubber Under ACFC	T.S. No. 3 & 4	4
Fiberglass	T.S. No. 13	5
Heat Scarification with Reclamite	T.S. No. 18 A	6
200/300 penetration	T.S. No. 10	8
Petromat	T.S. No. 12	12
Petroset in cracks	T.S. No. 15	12
Asbestos	T.S. No. 5	13
120/150 penetration LA Basin	T.S. No. 7	14
Emulsion Treated AC	T.S. No. 11	14
Reclamite flush	T.S. No. 17	15
Petroset flush	T.S. No. 14	16
Control sections	——	17
120/150 penetration Four Corners	T.S. No. 9	18
Reclamite in cracks	T.S. No. 16	20
40/50 penetration LA Basin	T.S. No. 8	20
2" AC, No ACFC		
Rubberized asphalt seal coat	T.S. No. 1	19
2" AC no ACFC	T.S. No. 6	64

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 22. COST OF OVERLAY PLUS TREATMENT (103)

	Cost/Yd^2	*Cost/Lane Mile
T.S. #11, Emultion Treated Base	$1.24	8,730
T.S. #7, 120/150 Pen L.A.	1.56	10,982
T.S. #8, 40/50 Pen L.A.	1.56	10,982
T.S. #9, 120/150 Pen 4-Corners	1.56	10,982
T.S. #10, 200/300 Pen L.A.	1.56	10,982
Control Section 1-¼" AC, ½" ACFC	1.56	10,982
T.S. #6, 2" AC no ACFC	1.58	11,123
T.S. #15, 16 & 17 Reclamite & Petroset in Cracks or as Flush	1.62	11,405
T.S. #14, Petroset as flush	1.65	11,616
T.S. #1, Rubberized Chip Seal	1.74	12,250
T.S. #5, Asbestos	1.81	12,742
T.S. #2 & 18A, Heater Scarified plus Reclamite or Petroset 1¼" AC, ½" ACFC	1.91	13,446
T.S. #3 & 4 Asphalt Rubber over 1¼" AC and under ½" ACFC	2.32	16,333
T.S. #12, Petromat	2.41	16,966
T.S. #13, Fiberglass	2.45	17,248
T.S. #18B, Heater Scarified plus Reclamite, 3"AC, ½" ACFC	3.29	23,162
3" AC, ½" ACFC	2.95	20,768
4" AC & ½" ACFC	3.74	26,330
7" AC & ½" ACFC	6.11	43,014

*Lane Mile equals 12' x 5280' = 7040 Square Yards

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 23. CONSTRUCTION AND MAINTENANCE COSTS OF FIVE RECOMMENDED ROAD TREATMENTS AND CONTROL SECTIONS (103)

Treatment	Construction Cost Per Square Yard	Construction Cost Plus Three Years Maintenance
200/300 Pen L.A.	$1.56	$1.91
Heater Scarified Plus Reclamate *or* Petroset	$1.91	$1.99
Asphalt-Rubber	$2.32	$2.36
Fiberglass	$2.45	$2.51
Control (Old Pavement Stripped)	$1.56	$2.19
Control (Old Pavement Not Stripped)	$1.56	$2.63

PAGE NUMBER
EPA-287 (Cin.) (6-76)

(millions of tons):

o Interstates	2.91
o State	9.89
o Municipal and county	6.98
o Private and Commercial	7.86
o Airports	0.58
o Other	0.87
	29.09

Under the simple assumption that 25 percent of this asphalt could have been replaced by ground tire rubber, 1976 paving applications could theoretically have consumed about 659 million 20-pound passenger car tires. The municipal and county shares of this market would have been about 175 million tires.

The unofficial position of the Association is that rubber should be added to asphalt pavements only if it

- will not affect product performance
- is economic.

Ground Rubber vs. New Rubber

As discussed previously, the prices paid by Sahuaro and Arizona Refining Company for ground rubber range from 6¢ to 25¢ per pound, plus freight.

There is some speculation that both Sahuaro and Arizona Refining might turn to formulations using new rubber in place of ground scrap rubber. Sahuaro is currently experimenting with a blend of new rubbers plus undisclosed materials. At this time, these materials are being tested to see if they can perform as an improved or equal alternate to the current formulation.

New rubber remains too expensive at this point. As of December 1978, the quotes for new rubber were:

Natural	56¢/pound
Synthetic:	
SBR 1500	46¢/pound
SBR 1712	37¢/pound

These prices have shown a steady upward trend--for example, the price of new natural has risen from 20¢ per pound in 1967.

The cost of grinding to the specifications of Sahuaro would be additional, although the process itself is trivial. The current suppliers to both Sahuaro and Arizona Refining have this capability, as do most new natural rubber suppliers.

Should there be an inversion in the historical relationship of ground scrap and new rubber prices, it is clear that both companies would be prepared to substitute new rubber in their formulation.

Rubber Reclaiming

The rubber reclaiming industry utilizes one of the oldest technologies available for recycling waste tires and other scrap rubber products. Major reclaim processes today represent only a slight modification of processes used at the end of the last century. Although the industry disposes of a significant number of tires annually (approximately ten million in recent years), it faces problems which restrict output and available markets:

- A relatively low grade of rubber is produced, containing several types of carbon black.
- Tire performance standards and increasingly specialized formulations for tire construction have led to a decreased use of whole tire reclaim in new tires.
- Freight rate structures appear to discriminate against reclaimed rubber.*
- Reclaim processes are highly labor intensive.
- Low operating margins have prevented a significant research and development program which might lead to the production of a superior product with reduced labor and energy requirements.
- Stringent air and water quality guidelines have contributed to the closing of a number of older facilities.**

Reclaiming is significantly less energy-intensive than virgin rubber production. Because of increased use of synthetic materials in making new tires after World War II, the reclaim industry has greatly decreased in size. However, higher oil prices should improve the competitive position of reclaim vis-a-vis the synthetics. Also, the Rubber Reclaimers Association is promoting asphalt-rubber uses, although a recent study concluded that reclaiming shows a net distribution of few or negligible benefits (68).

---

* National Association of Recycling Industries.

**U.S. Department of Commerce, U.S. Industrial Outlook, 1977, p. 156.

Through telephone interviews, we talked with representatives at three reclaim plants. These three reclaiming plants were Midwest Rubber Reclaim, Cahokia, Illinois; Goodyear's Reclamation Plant, Akron, Ohio; and Firestone's Xylos Reclamation Plant, Memphis, Tennessee. All three operations are large scale; the source of their tires are casing brokers. Firestone and Goodyear also receive casings from company-owned stores and retreaders. The final product for the reclaim operation is rubber to be used in the construction of new tires, as well as for tubing and insulation tapes. Table 24 shows the market shares for reclaimed rubber over the last twenty years.

Tire Derived Fuel (TDF)

There are several examples of current, proposed, or abandoned projects involving the burning of shredded tires or TDF. General Motors for several years used rubber as a supplement (10 to 15 percent) to coal (224), but recently abandoned the project when their supplier raised prices. GM found that total particulate emissions from tire burning are frequently much higher (60 percent) than from coal burning (the exception is the burning of properly sized rubber chips on a bed); the pollutants include zinc oxide and particulates resulting from the burning of the tire belting materials--but sulfur dioxide per BTU is lower for TDF. Properly handled, there was no odor problem or boiler damage (15).

A proposal has been advanced for fuel briquets of high calorific value to be composed of one part ground scrap tires, 2 to 4 parts cellulose wastes (such as sawdust, waste paper, straw) and a binder such as a moist cement or water (16). Apparently nothing like this is close to mass production at this time.

The Big "O" Tire company of Oakland, California has for several years run a project which involves gathering tires from dealers, shredding them, and trucking the intermediate product to a Georgia-Pacific mill in Ft. Bragg, California (230). The tires are shredded a second time at the mill and the resulting TDF is fed into "hog fuel burners" with various mill wastes to produce energy used by the mill. Both shredding operations apparently use a Rawls Tire Chopper. There is no comprehensive picture of the costs available, but it does appear that the entire operation has been made uneconomical by a sudden increase in the trucking fee from $125/load to $350/load, and operations are currently suspended pending resolution of this difficulty. Portland, Oregon provides TDF to Georgia-Pacific's mill in Toledo, Oregon (262).

The Minnesota Pollution Control Agency has contracted with the United Power Association of Elk River, Minnesota to test burn TDF with coal and to provide a written report of the results. The contractor analyzed the technical and economic feasibility of burning tires as a fuel supplement in coal boilers and also analyzed the effects of such burning on air quality. Three tests were conducted on separate days using 100 percent coal (baseline), 95 percent coal with 5 percent TDF, and 90 percent coal with 10 percent TDF.

TABLE 24. MARKET SHARES FOR RECLAIMED RUBBER*(68)

	1951	1961	1971
Tire Uses	17.7%	13,2%	6.4%
Non-Tire Uses	30.0%	15.4%	8.1%

*As a percentage of all rubber required for these two uses,

6-1/2"
9-1/2"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Measurements taken included: flue gas temperature, steam generation rate, steam pressure, particle concentration and size distribution, plume opacity, and concentration of O_2, CO, CO_2, SO_2, NO_X, and chlorides. Fly ash and bottom ash were analyzed for elemental sulfur, sodium, arsenic, boron, cadmium, iron, lead, manganese, nickel, zinc, phosphorus, phenolic compounds (such as C_6H_5OH), total dissolved solids, acidity, and chemical oxygen demand.

Although the final report had not been submitted, Donald Kyser of the Minnesota Pollution Control Agency provided preliminary findings on September 24, 1979. The "5 percent TDF" experiment, conducted at closer to 6 percent TDF, provided the best performance with an increase in steam output of 10 percent over 100 percent coal. The 10 percent TDF experiment resulted in steam production equal to 100 percent coal. In neither case was there any increase in boiler erosion. Advanced pollution control equipment such as a precipitator would be required to control a problem with "chunks of unburned carbon", but sulfur levels were lower. There were no problems with boilers, grate clogging, or other mechanical aspects.

Perhaps the most ambitious TDF project in the country has been proposed by the Ecological Energy Corporation of Concord, New Hampshire (221, 225, 254). This shredding operation would handle up to 24 million tires per year (an amount equivalent to almost all the waste passenger tires generated in New England). EEC has started by producing large size TDF for use in a local pulp mill. More finely ground TDF will be available as a fuel supplement to electric generating facilities in October 1979. EEC has a 10,000 ton purchase order with a five year contract for up to 100,000 tons per year from the Public Service Company of New Hampshire to provide what they call a "fuel pellet"--0.25 inch particle size shredded tires.

To collect the necessary supply of tires, EEC has contracts with a number of New England towns and eventually must reach agreements with almost all of the landfills in the region to reach full production. They also have arrangements with several large dealers and retreaders, such as Roland's Tire Service in New Bedford, Massachusetts. EEC leaves empty trailers at various sites, and periodically hauls down a replacement empty trailer and hauls the full one back to Concord. Presently they are operating with 12 trailers and one tractor. Eventually, the operation will require 80 to 90 trailers. EEC charges $20/ton plus freight to accept tires. The charge is meant to cover all collection and handling costs so that EEC can treat the tires as a zero-cost input to its process. The company presently has about 500,000 tires stockpiled at two locations and earlier this year experienced a serious setback with the loss of 200,000 tires in a fire.

Pyrolysis

One alternative to TDF for energy recovery is pyrolysis, or destructive distillation, proposed by a number of research groups in this country and overseas.

EPA-287 (Cin.)
(4-76)

TOSCO/Goodyear

The Oil Shale Corporation (TOSCO) was organized in 1955 to develop a commercial technology using an oil shale process invented in Sweden. The process, utilizing a solid-to-solid heat transfer, extracts oil, gas, other hydrocarbons and useful byproducts from the raw shale. With 35 patents, TOSCO is a U.S. leader in this energy supply technology and operates a large research facility at Rocky Flats, Colorado.

TOSCO became interested in the application of this technology to other organic materials, including scrap tires. In 1975, Goodyear and TOSCO entered into a joint venture to construct a large-scale pilot plant specifically for pyrolyzing scrap tires, in order to demonstrate the hardware and optimum process conditions for recovery of carbon black and liquid hydrocarbons of commercial quality.

The pilot plant, which we toured during our February 1979 site visit, is designed to handle 15 tons per day of scrap tires. Figure 13 provides a simplified flowchart of the TOSCO process, similar in most facets to the TOSCO II oil shale process, and reflecting many of the refinements developed over the years by the company.

Tires, including steel-belted radials, are shredded into 2 inch square chunks. The shredded tires are fed through a surge hopper and then into a 10-foot long pyrolysis drum, where the pieces contact ceramic balls heated to about 1200°F. The mixture is retained about one minute in an oxygen-free environment in the presence of steam, and the tires decompose to glass, steel, char, and hydrocarbon vapors.

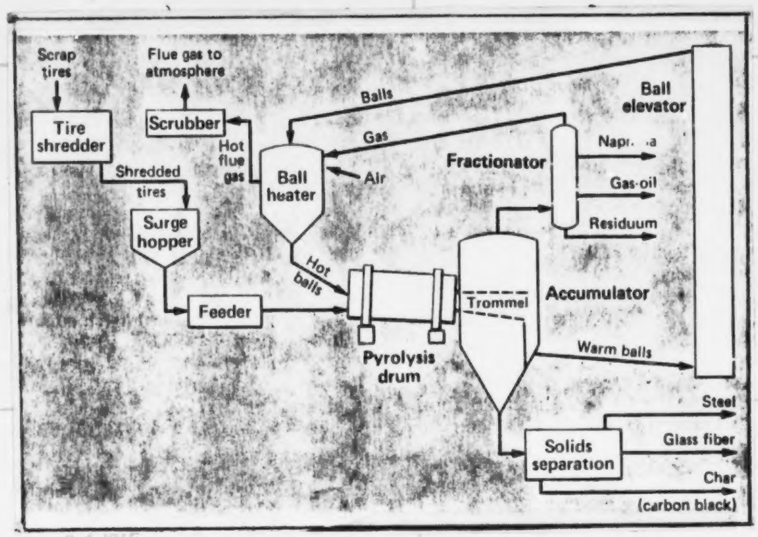
The potential recovery from a ton of shredded rubber feedstock is as follows:

Material	Production
Oil	3.4 bbl *
Carbon Black	575 lb
Steel	100 lb
Fiberglass	70-80 lb

Because of the perceived importance of carbon black recovery in the overall economics of the pyrolysis process, TOSCO has taken special measures to optimize recovery of this material. TOSCO claims that the carbon black recovered from the char is equivalent to GPF (general purpose furnace) grade carbon black and that the reinforcing properties are the same as those of the various grades of black currently used in tire production. "Standard rubber formulation tests, together with the use in making tires, has shown that the carbon black can be reused in portions of the tire according to the char's grade " (104).

---

*270 lbs/bbl.


Scrap tires
Flue gas to atmosphere
Tire shredder
Scrubber
Balls
Ball elevator
Gas
Hot flue gas
Shredded tires
Ball heater
Air
Fractionator
Napr. .a
Gas-oil
Residuum
Surge hopper
Hot balls
Accumulator
Feeder
Trommel
Pyrolysis drum
Warm balls
Steel
Solids separation
Glass fiber
Char
(carbon black)

9-1/8"

Figure 1. Flow chart for TOSCO pyrolysis process (153).

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

However, the carbon black produced does not meet the ash specifications of GPF black and should not be considered equal to that product. Given current product liability claims and the increasing number of carbon black formulations used in tire manufacture, it is unlikely that the black will be purchased by tire companies, even at a discount.

Goodyear and TOSCO once were considering a 300 tpd facility. These plans have been dropped, apparently because the expected maximum annual revenues from a 200 to 300 tpd facility are insufficient to offset the apparent risks of the project.

TOSCO is promoting the idea of a smaller facility (e.g. 25 tpd) for a municipality as a total systems approach to environmental management. Oil from the process could be used to heat municipal facilities; activated carbon could be produced for use at a municipal water treatment plant. The municipality would be reducing solid waste and landfill accumulation while producing two products with direct application to municipal operations.

Energy Recovery Research Group, Inc. (ERRG)

ERRG has (U.S. Patent 4,123,332) a process and equipment (see Figure 14) for treating carbonizable materials including shredded tires. The material is pyrolyzed in a horizontal reaction chamber free of oxygen at 750°- 1650°F. The system is designed to handle sawdust and powdered solid waste, as well as tires.

Tests of the system have been carried out with passenger car tires shredded to a maximum dimension of one inch. The tires comprised a normal mixture of bias, bias-belted, and radial tires including steel beads or bands.

The feed is continuously introduced to the pyrolysis chamber and encounters temperatures of 1600°F. Average residence time is 11.2 minutes. The reaction products and typical values from the pyrolysis and gas-vapor separation of a ton of feed are:

Liquid Hydrocarbons	814 lb or 3.01 bbl
Carbon Black	494 lb
Scrap Steel	44 lb

In addition, 618 pounds of fuel gases are produced with a displacement volume of 10280 cubic feet and 850 Btu/ft^3. About 40 percent of the gases are returned to heat the pyrolysis drum while the rest of the gas is wasted. Other than start-up fuel, however, the system is self-sufficient.

The liquid hydrocarbons available from the system are currently being analyzed to determine their potential value as raw materials in the production of further end-products.

The carbon black derivable from the process is stated to be of tire carcass quality. ERRG assumes that it may not be accepted by the tire

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD, BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
9-1/8"
6-1/2"

U.S. Patent Oct. 31, 1978 Sheet 1 of 2 4,123,332

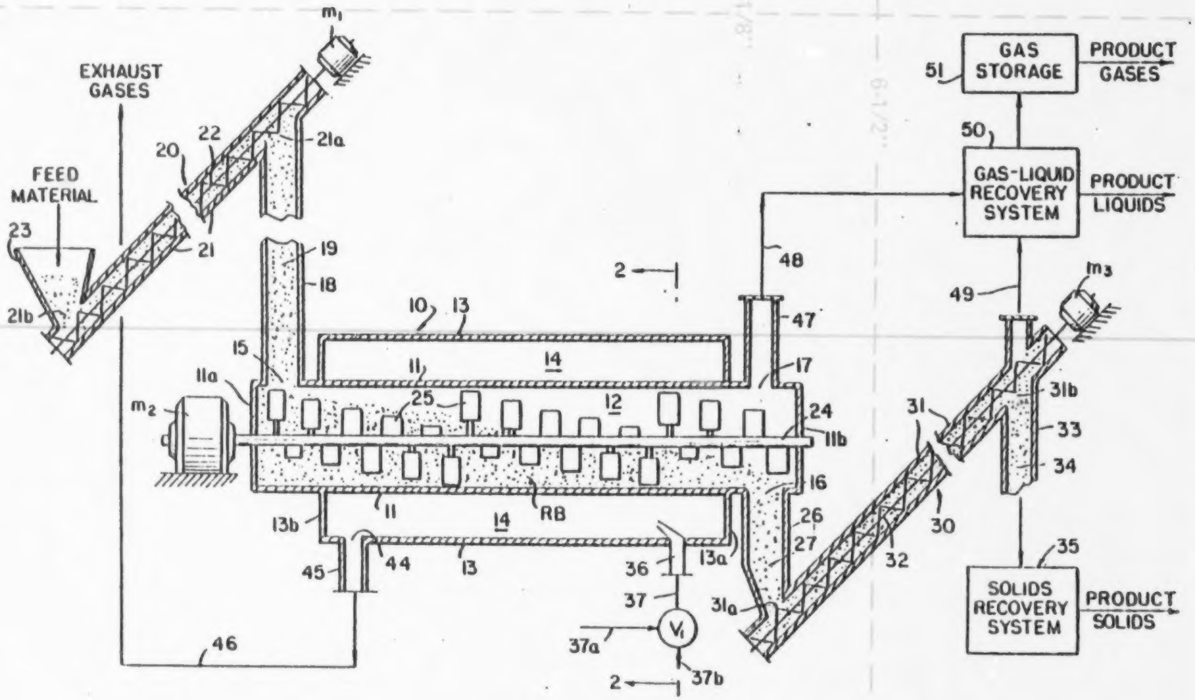

m1
EXHAUST GASES
FEED MATERIAL
23
20
22
21a
21
21b
19
18
15
11a
m2
10
13
11
14
25
12
17
47
48
24
11b
16
26
27
RB
13b
45
44
46
36
37
13a
37a
V1
37b
31a
2
31
30
32
31b
33
34
m3
49
GAS STORAGE
PRODUCT GASES
51
50
GAS-LIQUID RECOVERY SYSTEM
PRODUCT LIQUIDS
35
SOLIDS RECOVERY SYSTEM
PRODUCT SOLIDS

Figure 14

Source: U.S. Patent 4,123,332, Process, and Apparatus for Carbonizing a Comminuted Solid Carbonizable Material, October 31, 1978.

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

manufacturers, however, and they are investigating a number of other markets, principally copy paper and inks. On the other hand, there may be potential for an activated charcoal material suitable for water treatment and pollution control projects. As with the TOSCO process, however, the marketability of the carbon char component will have a deciding effect upon project economics. The current pilot plant, constructed of scrap materials, is designed to process 15 tpd. Capital costs for a commercial plant (25 tpd) are estimated at $16,000 per ton of daily capacity; it is probable this estimate is influenced by the ability of the company to utilize scrap materials to construct the pilot facility.

ERRG is prepared to pay as much as $10 per ton for scrap tires. This cost assumes reasonably sized, modular pyrolysis plants placed in close proximity to sources of scrap tires.

ERRG marketing strategy is to focus on specific segments of resource recovery (e.g. tires) and design small modular facilities involving minimal scaleup. Although the company is wary of involvement with municipal government, a logical market would appear to be municipalities which are willing to institute flow control to assure a steady supply of tires. However, the company would prefer to undertake joint ventures with private firms which can guarantee a supply of tires. This would be a 50/50 participation with 50 percent of revenues accruing to ERRG.

Alternative Energy Company (AEC)

Alternative Energy Company is the marketing arm for Guhl, Inc.; the latter holds the patents for the process discussed below. The company has proposed a comprehensive resource recovery and recycling program, the end product of which is blue-water gas (Figure 15). Utilizing the hydrocarbon makeup of the tire, at a temperature of 2300°F, water is added to produce COH_2 with an estimated BTU value of 283 BTU/cubic foot.*

The company recently constructed its first 25 tpd gasification unit, a scaleup from a smaller unit, at a small assembly plant in Oakland. Each ton of rubber is expected to yield:

141,000 cubic feet of blue-water gas, or 40,000,000 Btu's.

Of this total, 32,250 cubic feet, or 10,000,000 Btu's will be recycled to run the gasification system. AEC plans to add a Freon-generating facility to the system which will utilize waste heat from the blue-water gas generator, as well as any waste gas production to produce electricity and increase the overall efficiency of the system to an estimated 88 percent.

The standard module will be 25 tpd. This unit will generate 2,650,000 cubic feet of sellable gas per day, or 750 MM/BTU. There is also some recovery of scrap steel anticipated.

Based on AEC marketing surveys, the typical customer for blue-water gas uses 22 MM BTU/hour (518 MM BTU per day), whereas the modular plant

---

*Compare to natural gas: 1047 BTU/cubic foot.

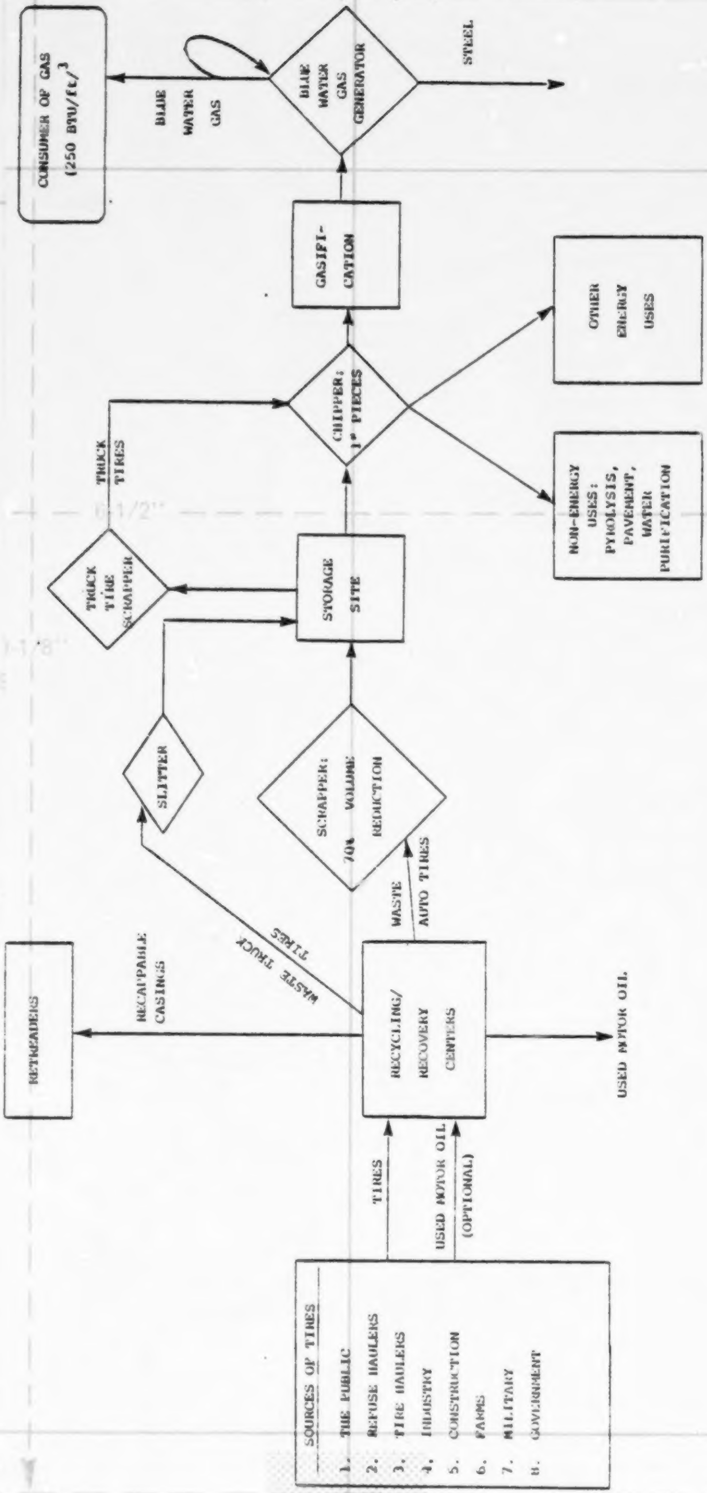

SOURCES OF TIRES
1. THE PUBLIC
2. REFUSE HAULERS
3. TIRE HAULERS
4. INDUSTRY
5. CONSTRUCTION
6. FARMS
7. MILITARY
8. GOVERNMENT
TIRES
USED MOTOR OIL (OPTIONAL)
RECYCLING/ RECOVERY CENTERS
USED MOTOR OIL
RECAPPABLE CASINGS
RETREADERS
WASTE TRUCK TIRES
WASTE AUTO TIRES
SLITTER
SCRAPPER: 70% VOLUME REDUCTION
STORAGE SITE
TRUCK TIRE SCRAPPER
TRUCK TIRES
CHIPPER: 1" PIECES
NON-ENERGY USES: PYROLYSIS, PAVEMENT, WATER PURIFICATION
OTHER ENERGY USES
GASIFI-CATION
BLUE WATER GAS GENERATOR
STEEL
BLUE WATER GAS
CONSUMER OF GAS (250 BTU/ft^3)

Figure 15

BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

is designed at 25 tpd (750 MM BTU per day). The feed of tires can be adjusted accordingly to reduce waste gas. The company feels that very few potential customers will exceed a billion BTU/day.

AEC has also developed a machine for the size reduction of tires. The AEC 'scrapper' (130) is a very low horsepower (10 hp) machine with reversible cutting blades, handling about 100 to 130 tires per hour. Size reduction is about 70 percent.

Other Pyrolysis Approaches

Batchelor Robinson Metals and Chemicals completed pilot plant studies of a pyrolysis process in 1978, which were reported to be encouraging. At that time, they were considering a proposal to build a commercial size plant processing 50,000 metric tons of shredded rubber per year, and producing 20,000 tons of refined oil, 15,000 tons of char, and about 7,000 tons of steel wire. The char could be sold as pulverized solid fuel, and the steel wire as scrap. The process takes place at temperatures of 850 to 925°F. Estimated 1978 capital cost is 2.5 million pounds (4.25 million dollars),* or about $30,000 per input English ton (151 tpd).

Firestone has studied pyrolysis since 1968. Scrap rubber is fed to a rotary calciner and char and oil are collected in a knock-out drum and condenser respectively. The company emphasizes that pyrolysis is primarily a carbon black recovery process, the quality of black being determined by the type of black originally in the scrap. The most efficient procedure for recovering high quality black is pyrolysis in an inert atmosphere at high temperatures. This black may be improved by acid leaching of the ash--this difficult and expensive procedure improves the reinforcing properties of the char black. According to Firestone, oxidative pyrolysis does not significantly improve the black, whereas pyrolysis in a steam atmosphere produces a char with potential use as activated carbon.

The products obtained from a pyrolysis experiment undertaken by the Bureau of Mines, Firestone, and the American Gas Association were as follows:

	Product, Weight (percent)	
	500 C (932 F)	900 C (1652 F)
Residue	41.6	55.4
Heavy Oil	44.0	13.2
Light Oil	3.6	6.0
Liquor	2.9	2.2
Free Ammonia	0.2	0.1
Gas	5.0	19.4

---

*Assuming $1.70 per pound sterling.

Nippon Zeon Company (19) has developed a thermal cracking process enabling recovery of 52 percent oil, 33.6 percent char, and 14.4 percent gas from tires. No crushing of the tires is required, and there is no significant pollution. A fluidized bed reactor is used, with temperatures of 650 to 1100°F. The economics of the process are largely dependent on scale. The total operating cost of a one ton/hour plant is $140.05/ton, whereas a four ton/hour plant incurs costs of $66.39 per ton (both 1979 dollars). A small pilot plant based on the process is operating in Japan.

The "H-Rubber Process" has been developed by Hydrocarbon Research, Inc. Scrap rubber pieces in oil are heated in a boiling bed reactor in an atmosphere of hydrogen. Products are fuel gas, naphtha, carbon black, and oil. Because of the hydrogen in the atmosphere, hydrodesulfurization of the fuel takes place, resulting in a low-sulfur fuel oil.

There are numerous brief references in the literature to pyrolysis processes which are variations of those discussed above including:

- heating at 1382°F with superheated steam in a cylindrical reactor tower (12)
- flash pyrolysis at 1200°F in a tube reactor (17)
- powdering and pyrolysis of tires in a fluidized bed at 750°F to 925°F (21, 30)
- irradiation of tires with microwave in steam at 750°F to 1650°F. (31)

All of these processes produce significant quantities of carbon black. In all pyrolysis systems, an increase in the temperature will result in higher gas yields, but even at the lower temperatures the reaction should be self-sustaining once underway.

Other Uses of Shredded Tires

Firestone and others have studied Depolymerized Scrap Rubber (DSR) techniques. Scrap vulcanized rubber is heated in an aromatic processing oil, resulting in a dispersion of carbon black in heavy oil. The processing oil acts as a solvent and heat-transfer medium, as well as a chain transfer agent. The contained carbon black can be separated from the oil by solvent extraction of the heavy oil, but this is a difficult process. Contaminants are easily removed because they do not dissolve. The authors suggest the possible use of DSR as a rubber compounding ingredient or for large-volume non-rubber use, such as fuel oil or asphalt extender.

A study by Firestone and Rutgers suggested that there are several microorganisms which may reduce the size of rubber particles, in the process freeing hydrocarbons. However, none of these microorganisms will "selectively and completely cleave sulfur bonds" and growth of the microorganisms was eventually suppressed by other ingredients in the tire, such as zinc oxide.

PAGE NUMBER
EPA-287 (Cin)
(4-76)

The use of ground scrap rubber as a mulch has been proposed, although it is expensive relative to other mulches. Experimental data indicate that ground rubber may prevent wood growth in soybean and other fields. However, the rubber must be used carefully to avoid toxic effects on the plants.

Other proposed uses are:

- aerated rubber as a soil conditioner to affect water retention in various types of soil
- shredded tires and shredded polystyrene as an oil spill cleaning agent -- tire buffings also have some potential in this area
- water purification materials.

None of these techniques may be considered both economical and sufficiently refined at this point for widespread application.

Tire Splitting

The tire splitting industry, consisting of a very few companies, produces various industrial products die-cut from obsolete tires. Products include gaskets, shims, insulators, doormats, conveyor rollers, belt pieces, and various other items for the automotive industry. In 1972 it was estimated that the industry utilized about 29,000 tons of tires, of which 7,000 tons went into the die-cut products, 18,000 tons were sold to rubber reclaimers, and 4,000 tons went to waste disposal. It is unlikely that these tonnages have changed significantly over the past seven years.

Splitters receive tires in both graded and ungraded lots, the latter category accepted only from mass marketers such as J. C. Penney, Sears, and Montgomery Ward. Tires in ungraded lots are segregated, and the recappable casings are sold to retreaders. The remaining tires are die-cut, and the scraps from this operation are ground and sold to rubber reclaimers. The splitter is responsible for the disposal of all tires which cannot be recycled. Thus, when purchasing scrap tires on the open market, splitters generally choose only those appropriate for their uses.

Steel-belted radials are a particular problem for tire splitters, and partially account for a lack of growth in the industry. Steel-belted radials which cannot be sold as retreadable casings are currently landfilled, as they are not economically usable as raw materials. Although some firms have developed methods which enable them to remove the steel, these are generally considered marginal operations.

Figure 16 illustrates inputs and product flows for a typical tire splitter, showing the various sources of tires. Outputs include disposal to landfill, ground rubber sold to reclaimers, and products from split tires. Splitters feel that there are potential new markets for split tire products as well as ground rubber (e.g. rubberized asphalt), but raw materials costs currently render these alternatives not competitive.

EPA-287 (Cin.)
(4-76)

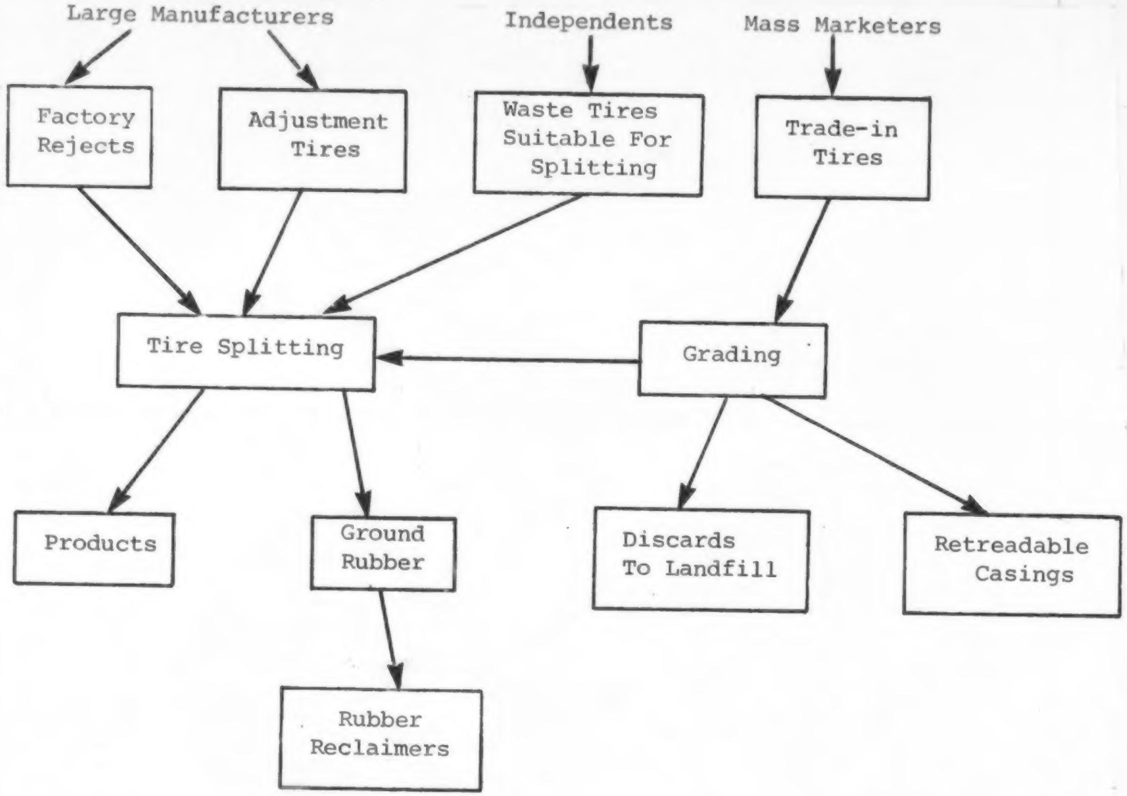

Large Manufacturers
Independents
Mass Marketers
Factory Rejects
Adjustment Tires
Waste Tires Suitable For Splitting
Trade-in Tires
Tire Splitting
Grading
Products
Ground Rubber
Discards To Landfill
Retreadable Casings
Rubber Reclaimers

Figure 16. Inputs and product flows for a typical tire splitter.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD: BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

USES OF WHOLE TIRES

Whole Tires as Fuel

There are a few instances of whole tires being burned for their fuel value, usually as a small percentage of the total mix being burned. Goodyear has run at least two experimental boilers using whole tires. One is a cyclone furnace which creates an inward vortex which facilitates complete combustion of whatever fuel is being used. This furnace has a capacity of 36 tons per day of tires and produces 25,000 pounds of steam at 250 psi during each hour of operation. If this furnace were used on a continuing basis, it could consume up to 7,200,000 passenger tires per year. No cost data are available for this process, but the unit has not been successful enough for widespread application in the U.S..

Goodyear's second boiler is a very large and very old wet-bottom boiler which burns whole tires with coal as 10 percent of the fuel mix. They have tested tire percentages considerably higher than 10 percent, but the 10 percent level seems to work best. They have encountered no serious air pollution difficulties, but this could be due to unusual boiler characteristics and the fact that they are classified as a power plant as opposed to the more stringent classification of incinerators. Since this is the only boiler of its kind operating in the country, the application is of limited importance. Perhaps more interesting than the technology used in this case is the intricate collection and resource recovery system operated by Goodyear in the Akron area. Discarded tires are collected from dealerships for retreading at central facilities. Rejects are processed along with factory rejects at a Goodyear rubber reclaim facility. Those tires, generally steel belted, which are not processed into reclaim are used as fuel in the boiler which provides steam to Goodyear facilities. Since the motivation for burning the tires has been disposal rather than energy, a Goodyear project representative indicated to us that no specific figures are available on the economics of this process.

A number of resource recovery plants operating around the country presumably burn whole tires with other refuse. We spoke to a representative of Refuse Energy Systems Company (RESCO) in Saugus, Massachusetts, who said that they get a few tires in general waste and an occasional truckload from dealers which they put to one side and feed in gradually with other waste. RESCO has had no problems with this procedure, but the quantity of tires disposed of in this manner is insignificant.

Artificial Reefs

Every major tire company has been involved with one or more artificial reef programs. Several thousand reefs have been or are being built along the East and Gulf Coasts, incorporating as many as three million tires per reef. Whole scrap tires become rapidly encrusted with barnacles and other stationary marine life, thus forming a reef as attractive to many species of fish as natural reefs. The development of these reefs can be beneficial to commercial fishermen and recreational anglers.

A number of configurations have been tested, including one-, two-, three-, and eight-tire units fabricated manually by volunteers, as well as large units manufactured by government and industry. To construct these latter reefs, tires are pneumatically punched to reduce buoyancy, compressed, bundled, and weighted with concrete. Baling systems have also been developed (253). The optimum density of reefs in tires per acre has not yet deen defined.

The simpler designs may cost from 36¢ to 40¢ per tire, plus donated labor whereas more sophisticated approaches may cost up to $4.16 (1976$) per tire. Both estimates assume free tires are delivered onsite, which may be less feasible in the future. The volunteer labor often comes from sport fishing societies or local governments, who eventually receive many of the benefits.

The potential use of tires in reefs has been estimated as at least 1.5 million tires per year, and the upper limit for reef applications is unknown. Freshwater uses are receiving considerable attention. Overall, the use of scrap tires for reefs is a viable, but limited, disposal option.

Since the reefs are placed in open water, there is no easy mechanism for charging the beneficiaries to cover the costs of the improved fish habitats. Therefore, reefs are generally developed as low-cost operations with in-kind contributions by the eventual recipients of the benefits. The net benefits may be very large, but they are outside the conventional market structure, and very hard to assess.

Breakwaters

Floating tire breakwaters (FTB) have been developed to protect small boat marinas, shorelines subject to erosion and even marshlands. Goodyear has been particularly active in this area, awarding grants to several universities to study breakwater design, and constructing a dock protection breakwater in Akron and a similar device in Chicago's Diversey Harbor.

Several configurations of tire bundles have been tried. The most successful in terms of flotation and effectiveness is a basic 18-tire modular unit (Figure 17) which can be connected in series to form unlimited rows of varying lengths. Two binding lines are required to keep the bundles together--after experimentation with chain, nylon rope, and steel cables, all of which have durability problems in salt water or which damage the tires - conveyor belt edging material is now used (253). The edging is a waste product from conveyor belt manufacture and costs about 5¢ per foot of material.

Breakwaters built of passenger tires will generally suppress about 75-80 percent of waves up to five feet in height. Truck tires suppress larger waves. Breakwaters of four rows of tire bundles (about 25 feet wide) are generally used.

There are about 75 FTBs in the United States, the average size being 300 feet by 25 feet, and using 3,400 tires. The present use of about 250,000 tires is small relative to the number of tires annually generated. An FTB is

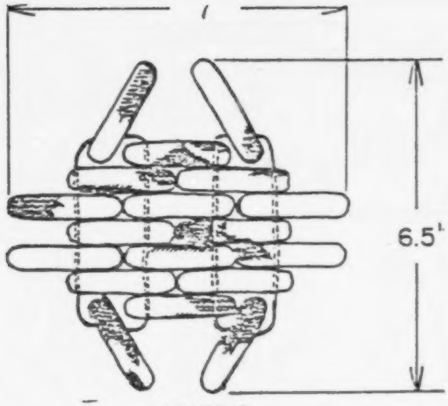
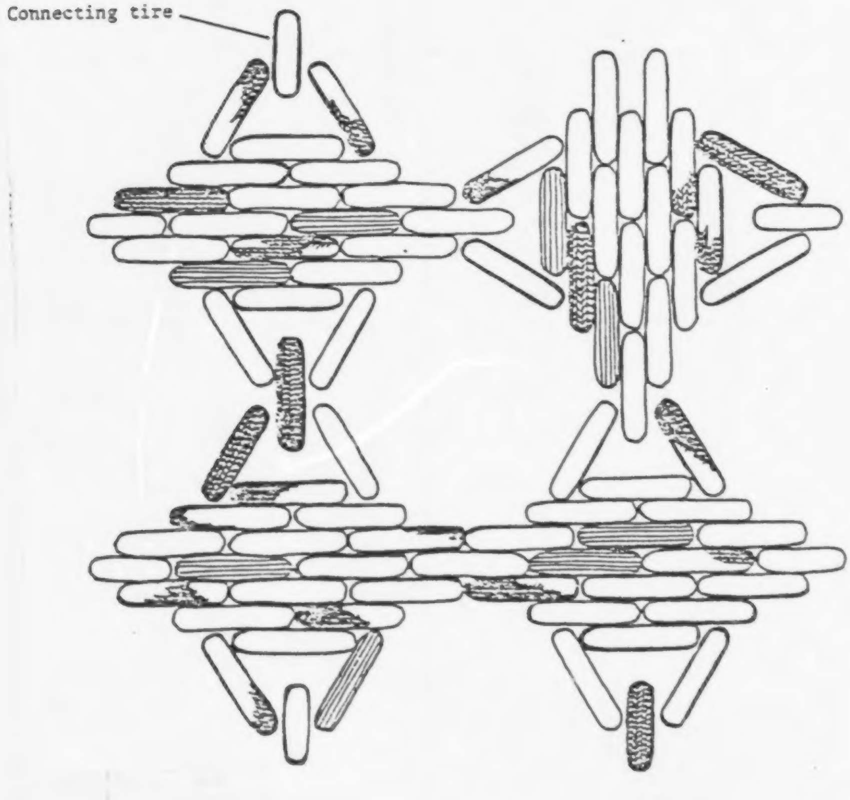


FIGURE 2

Modular Building Unit Shown as Installed



Modular Units Connected to Form Mat

Figure 17. 18-Tire floating tire breakwater configuration.

SOURCE: (253)

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

under construction in Lake Pontchartrain, Louisiana that will be two miles long and 500 feet wide. It will use about 230,000 tires.

Cost components include tires and transportation (both generally free), nylon bolts to bind the edging material, flotation material to maintain long-term flotation, moorings, navigational markers, skilled labor, and boat rental. Reasonable assumptions for the costs of these items lead to a lower bound estimate of identifiable costs of $13.50 per linear foot, assuming free tires. Other estimates in the literature range up to $30-50 per linear foot.* These latter estimates would appear to be upper bound costs. There will also be annual maintenance costs to clean the FTB of debris, replace broken bindings, reset moorings, clean marine growth, etc.

Costs for conventional breakwaters have been estimated at $100 to $500 per linear foot for wooden bulkheads, and up to $1,000 per linear foot for a rock breakwater. Even assuming paid skilled labor for tire breakwater construction, rather than volunteer labor is as is often the case, FTBs are quite inexpensive.

There were some early problems with improper binding materials that failed. Also, without flotation material, marine growth eventually causes the tires to sink, as happened with a number of early breakwaters. These early failures have impeded the widespread introduction of the concept, and only one firm specializes in the construction of FTBs.

The breakwaters are limited to semi-sheltered harbors and bays with four to five foot waves, although some experimentation with ocean use is underway, using primarily truck tires, and different bundling and configuration techniques. Long-term demand, however, will be fairly limited, given the smaller waves for which FTBs are effective. Assuming a four-fold increase for FTBs from the present 15-20 per year at an average of 300 feet/FTB, 240,000 tires per year would be needed. This is, therefore, a limited use for old tires.

Baling of Whole Tires

One reason for shredding tires is to reduce the volume and thus increase the number of tires which can be transported in a truckload. However, it may be possible to get sufficient savings in volume by bailing the whole tires. It is also suggested that baling will reduce storage and handling costs. One company, International Baler, produces hardware for this application and one unit is currently being used in support of an artificial reef in the Tampa Bay area. Use of this baling technology is not widespread.

Crash Barriers

Scrap tires have been tested as impact barriers for divider strips, bridge abutments, support posts, guardrails, and overpasses. The barriers are constructed of horizontally stacked tires fastened together with steel cables in tension. Experimental head-on and side angle collisions suggest that the barriers may be effective in reducing injury. However, the barriers are not suitable for small lightweight vehicles, and additional tests are needed to improve their performance. No comprehensive estimates of costs for these barriers are available in the literature. The barriers have not been approved as a highway hardware item.

---

*For instance, Maryland has been using tires for shoreline protection at $30/linear foot (146).

SECTION 5

ECONOMICS OF TWO TECHNICAL OPTIONS:
TIRE-DERIVED FUEL AND ASPHALT-RUBBER TREATMENTS

INTRODUCTION

Tire derived fuel and rubberized asphalt have been identified as technologies which could utilize a considerable proportion of the scrap tires generated annually. These alternatives are attractive because they depend on basically proven size reduction technologies to make a product used either as a fuel or a component in roads. The second advantage that these technologies have in common is the potential for widespread use. Boilers and roads are common and relatively dispersed networks of producers and users may be possible if the economics are favorable.

The analyses presented here are to evaluate the economic feasibility of the options and possible impacts of changes in public policy. Before any subsidy, either direct or indirect, can be proposed, more detailed analysis of these and other technologies would have to be completed. Of particular importance would be analyses of the existing rubber reclaim industries. The level of competition among existing and innovative scrap tire industries should be examined with particular emphasis on how proposed economic incentive programs would shift demands.

The issue of competition between potential users of scrap tires is an important one. As the analysis that follows indicates, the high cost of transportation and handling make many recovery schemes practical only in urban areas where the concentration of used tires is high.

However, most major urban areas have a network of jockeys and retreaders in place who are already collecting the tires which they can collect economically. While the economics for new uses--such as TDF or rubberized asphalt--may be very different, making a marginally greater number of tires economically usable, the new user will have to compete with the existing established industries for the easily collectable tires. While it may be possible to partially break into this existing network, major penetration is unlikely. Thus in making detailed supply availability studies for the siting of any resource recovery facility to utilize tires, it will be very important to carefully estimate the existing used tire market in an area and to determine the actual cost of collecting marginal tires rather than assuming no competition.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

ECONOMIC ANALYSIS OF TIRE DERIVED FUEL

As described in Section 4, one use for waste tires is as fuel--either alone or, more commonly, in combination with other fuels. Tires have an energy content in the neighborhood of 14,000 to 15,000 Btu's per pound. This is compared to an average 12,000 Btu's per pound for coal. At present, most experiments involve tires burned whole or shredded and mixed with coal at a 1:5 to 1:10 ratio. Burning tires whole requires very specialized conditions; it does not appear to be an option for large scale scrap tire use. This section, therefore, analyzes the economics of using shredded tires as fuel. Several of the companies who are currently looking into the production of tire derived fuel (TDF) or who have looked into it in the past were mentioned in Section 4.

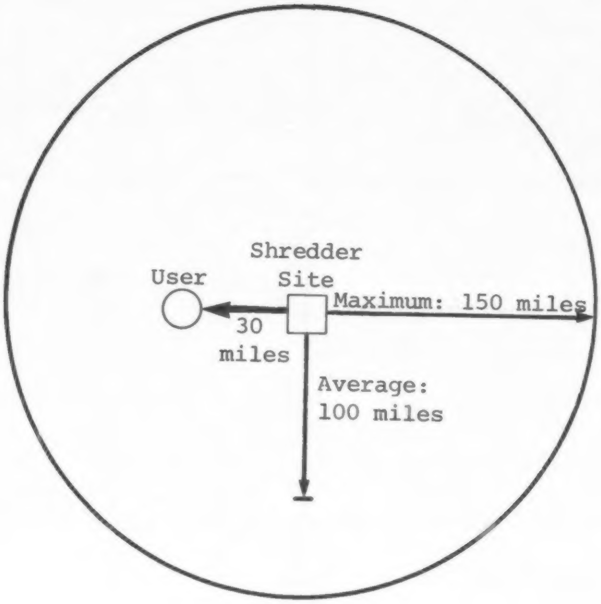
In performing this economic analysis, tire derived fuel is assumed to be composed of tire pieces, some of which are greater than 1.5 inches square. While pulverized or pelletized tires could be attractive, they have not been used to date; thus, our analysis does not include suspension on fluidized bed furnaces (or other methods) using pulverized or pelletized coal, but it is limited generally to fuel sizes compatable with grate furnaces. For this reason, near-term industrial applications should be more important than electric power generation. The graphs and data presented are meant for comparative analysis only and should not be used in the prediction of profit or loss for any one firm.

The analysis starts with a standard abstraction--a featureless plain with a constant population (and tire) density and with straight-line travel possible between any two points. At one site on this plain, we have placed a facility for using the TDF: reasonably nearby, we place the processing plant, with shredder. Because of the constant tire density and unit transport costs, the shredder operator will collect tires from a circular service area, out to some maximum economic radius.

Analysis of the Base Case

The system as designed has one major degree of freedom: the collection of tires. Given the costs as defined, and the prices paid for fuel produced, the basic question is how much the shredding firm can pay or must charge for the tires it accepts for disposal. A related concern is how high a fraction of tires in the service area must be received--essentially a comparison of the density of scrap tires (tires/mi^2) and the collection density required to reach the planned shredder throughout.

While Figure 18 presents a picture of the service area and summarizes the results, Figure 19 and Table 25 show the assumptions and calculations for this base case. Under this analysis, tires have a positive value delivered to the shredder site, but this is quickly overwhelmed by the costs of getting them there. For the operation to be profitable, the average tire arriving from 100 miles must have associated reserves of 25¢, and the generator of a marginal tire 150 miles away must pay 33¢. This is similar to the current


User
Shredder Site
Maximum: 150 miles
30 miles
Average: 100 miles

	Worth to Shredder Operator
Marginal Tire Delivered to Shredder	12.5¢
Marginal Tire at 150 Miles	-32.5¢
Average Tire Delivered to Shredder	6.5¢
Average Tire at Average Distance	-23.5¢

Required Number of Tires Annually:

Equivalent to all tires from	800,000 population
50% of tires from	1,600,000 population
10% of tires from	8,000,000 population

Figure 18. Collection area for the base case.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

1. Transportation costs--assuming truck, including loading/dumping *

From Chapter 3

Truck,	< 100 miles whole	40¢/ton-mile or .44¢/tire-mile
	< 100 miles shredded	25¢/ton-mile or .28¢/tire-mile
	> 100 miles whole	13¢/ton-mile or .14¢/tire-mile
	> 100 miles shredded	10¢/ton-mile or .11¢/tire-mile

Since this analysis is working primarily in the 0-200 mile range, using trucks, for simplicity we will use a middle value.

Whole tires	$.0030/tire-mile
Shredded tires	$.0020/tire-mile

2. Sales price

Coal, nationally	$.94/million Btu
Tires	15% discount, delivered at plant
National	$.80/million Btu

At 14000 Btu/lb.,** this becomes

National sales price	$.25/tire

3. The shredder

A median performance shredder, based on the data in Exhibit 4-3 would have the following annual costs at 1 shift/day, 5 day operation:

Capital Cost:	$50,000
Equivalent Annual Cost:	$13,900/year+
Labor (1.5 persons):	$22,500/year
Electricity	$ 6,500/year
Maintenance:	$ 5,000/year
Total:	$47,900/year
Design Throughput:	500 tires/hour
Assumed actual throughput:	400 tires/hour, or 800,000 tires/year
Assumed cost per tire:	5.9¢/tire

*In fact, the cost would decrease continuously as distance increased, rather than in a step function.

**22 lb/tire.

+7year life, 20% discount rate pre-tax.

Figure 19. Base case assumptions and calculations: tire derived fuel.

TYPING GUIDE SHEET
EPA-287 (Cin.)
(4-76)

Figure 19
(continued)

4. Inventory costs

3 months, 200,000 tires. Assumed delivered free, but require 1 acre of land for storage.

5. Total land for shredder, administration building, parking, inventory = 2.5 acres, or $500/year.

6. Structure costs: $11,600/year

7. Total direct facility costs: $60,000/year

8. Overhead/administration: 50% of direct = $30,000/year

9. Profits before tax: approximately 10% of total cost: $10,000/year

Total facility cost:	$100,000/year = $.125/tire
Marginal cost* (labor, electricity, maintenance, overhead);	$ 51,700/year = $.065/tire

10. Transport of shredded tires to power plant: 30 miles @ .2¢/mile = $.06/tire.

11. Transport assumptions:

Circular service area, constant tire density, 150 mile radius. This means 100 miles is the average transportation distance.

12. Base case results

	Average Tire	Marginal Tire
Revenues	$.25	$.25
Costs		
Initial transport	3¢/tire-mile	3¢/tire-mile
Processing	12.5¢/tire	6.5¢/tire
Shredded transport	6¢/tire	6¢/tire
value of tire delivered to shredder	6.5¢	12.5¢
at average distance	-23.5¢	-17.5¢
at maximum distance	-38.5¢	-32.5¢

---

*Actually, the average variable cost.

Figure 19
(continued)

Collection rate to reach capacity 11 tires/mi^2

Generation:*	Massachusetts	741 tires/mi^2
	Ohio	262 tires/mi^2
	California	134 tires/mi^2
	North Carolina	110 tires/mi^2
	Oklahoma	39 tires/mi^2
	Wyoming	4 tires/mi^2

*Assumed equal to population density.

estimated cost for proper landfill disposal (30 to 50¢/tire). The system proposed here would be an unreasonable option for users at over 200 miles, where even a marginal tire would only be accepted by the shredder operator if the generator paid 47.5¢. If the generator had to cover average costs, he would have to pay 53.5¢ to the shredder firm. The shredder firm can be profitable if it can reach capacity within the 150 miles, but not beyond that.

Increased Fuel Value

If we use a considerably higher "New England" value for fuel of 44¢/tire, the results shift somewhat, as shown in Table 26. Obviously, the values of tires at the shredder rise considerably, as do the value of tires farther away (costs stay constant).

More interesting, though is the case where the scrap tires generator can get free disposal. In the base case, the shredder firm could offer such disposal within 42 miles and still cover marginal costs given our assumptions. In this high fuel value scenario, this radius increases to over 100 miles, and the system could probably operate effectively at that radius, given a reasonable tire density. Where the cost of energy is high, the shredder system could apparently operate without payment by the generating firms.

Cost Reduction in Processing

There are two ways in which costs could be reduced in the processing stage: increased utilization of installed capacity and increased capacity, given apparent economies of scale. Table 27 shows the effect of these improvements on processing costs. The changes are not large--total system economics are dominated by transportation costs and input and output revenues. A change of 3¢/tire in average cost, for example, is only equal to a change of 12 percent in fuel value or of 10 miles in transport radius.

Cost Reductions in Transportation

The transportation costs on the input side are based on truck transport of whole tires. Average transport cost for the base case is 30¢/tire. If these tires were all shredded, the result would be a savings of 10¢/tire in transport cost, well above the marginal cost of our fixed, large scale shredder. However, estimates in LaCrosse for the costs of low-volume tire splitting were 15-20¢/tire, which becomes attractive at the periphery of the service area only. Figure 20 shows the value to generators of splitting before pickup by the shredder operator, based on transport cost savings. These should be compared to the costs of splitting for the volume provided, to see whether the investment would be profitable.

Transport by rail is much cheaper, if full cars can be used. Rail transport of tires costs .07¢/tire-mile for whole tires, and .05¢/tire-mile for shredded tires. Delivery to the railhead is likely to cost at least 3-4¢/tire (possibly much more), but the total transport cost for 100 miles would still be reduced, from 45¢ in the base case (30¢ shredded) to 11¢ with

TABLE 25. SIZE REDUCTION MACHINERS: PIECES GREATER THAN 1.5 INCHES SQUARE

Company	Capital and Operating Cost of Process*	Maintenance Cost of Machine*	Machine Power	Processing Rate
Rawls	$30,610	$7,200/yr	25 hp	360 tires/hr
Shred-Pax	$64,500	$5,160/yr	---**	400 tires/hr
Saturn	$60,350	$5,400/yr	150 hp	600 tires/hr
Tire-Gator	$75,000	$76,000/yr	30 hp	1,900 tires/hr
Tire-Gon	$35,500	$3,552/yr	100 hp	600 tires/hr

*Based on an assumption of one 8-hour shift per working day and 250 working days per year.

**Power not available, however, electrical costs are equal to $3,880 per year.

TABLE 26. RESULTS WITH ALTERNATIVE FUEL VALUES

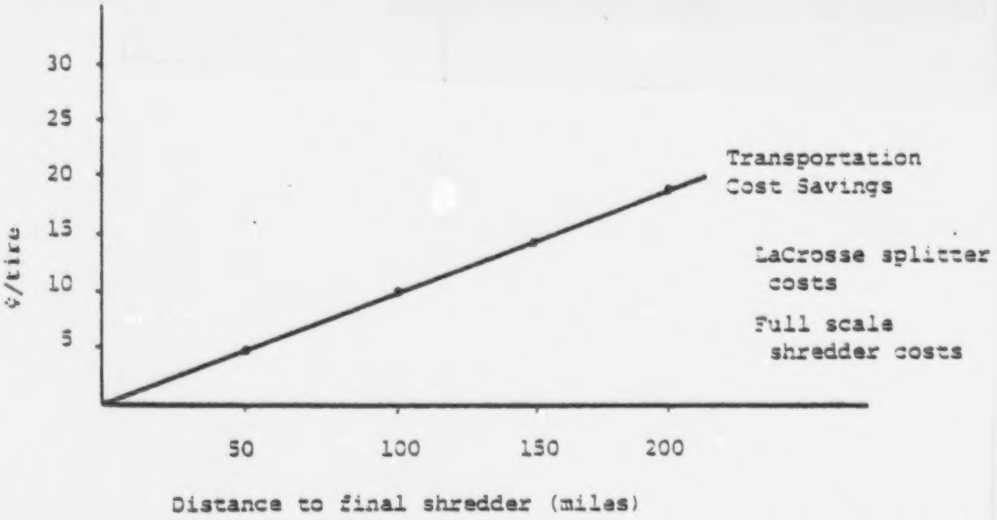
	Base Case	High Value
Value delivered shredded to burner	25¢/tire	44¢/tire
Value of average tires at shredder before shredding*	6.5¢/tire	25.5¢/tire
Value of marginal tires at shredder before shredding	12.5¢/tire	31.5¢/tire
Zero value distance, average tire	22 miles	85 miles
Zero value distance, marginal tire	42 miles	105 miles
Tire density required to meet capacity with marginal tire value = zero at maximum radius	144 tires/mi^2	23 tires/mi^2

*Sale price minus transport and shredding costs.

TABLE 27. PROCESSING COST REDUCTION

	Average Cost	Marginal Cost
Base Case	12.5¢	6.5¢
Two shifts*	10.1¢	6.5¢
Doubled capacity**	10.9¢	5.7¢
Fourfold capacity**	9.5¢	4.9¢

*No overtime premiums. Profit/tire constant
**Assuming total cost = α(Quantity)$^{.8}$, or moderate economies of scale for both average and marginal cost components.



If splitting costs are below the transport cost at the point of interest, splitting would be profitable; if above, it is cheaper to transport first.

Figure 20. Value of splitting before transport (reduced transport cost).

rail (8¢ shredded).* The three main problems, though, are the need for a rail siding at each end, the probable increase in actual mileage (as opposed to straight line distance) and the requirement for 14-18 tons as a whole tire load, or 40-50 tons of shredded tires per load. Rail apparently makes sense for long-haul shipment, with shredding for distances over 500 miles; for small facilities such as proposed here, rail will generally not be the mode selected.

Multivariate Analysis and Optimization

The real question for the shredder operator throughout this analysis has been "can he find enough tires at a reasonable price, and what system scale, service area, and pricing policies make sense?" In this section, we model the costs of his operation and the demand for his services to optimize scale and service radius given a demand curve. Figure 21 shows the system design and provides some assumptions; Figure 22 shows the model equations.

Equation 1 is the basic decision rule for generators supplying tires to the shredder. The quantity for any ring from (r) to (r + dr) is the number of tires $[2\pi Ddr]$** times the individual tire supply curve $[\alpha (P_r - P_o)^{\beta_2}]$ where we have assumed a constant elasticity supply curve above a floor price, established by the cost of landfill disposal.

Equation 2 integrates from the shredder outward to get total supply. Equation 3 defines the flat transport cost per tire mile, and equation 4 shows the processing cost function. Here, we have assumed $\beta_1 = 1$ to make integration possible in closed form. Smaller values of β_1 (economies of scale) would imply somewhat larger facilities than analyzed here.

Equation 5 defines the price at each ring, which is equal to the value after shredding (V) minus the cost of shredding (C_S) and transportation ($C_T r$). Equation 6 looks at the maximum radius, R_{max}, where Q falls to zero as $P_r = P_o$. This is the limit for the integral in (2).

Equations 7 and 8 are substitutions, with the integration performed by parts in equation 9, and evaluated in equation 10. Note that $k_2 = C_T r$ at R_{max}, so the upper terms drop out. Algebraic manipulations provide equations 11 and 12, with k_1 and k_2 resubstituted.

The properties of equation 12 are as expected. As the tire density (D) or selection rate (α) rise, so does system scale. The same is true if the transportation cost (C_T) is lowered, following an inverse square approach. If the net effective value of the delivered tire ($V - C_S - P_o$) rise, so does the quantity--exponentially. Elasticity increases will generally lead to increased quantities, for any reasonable delivered values.

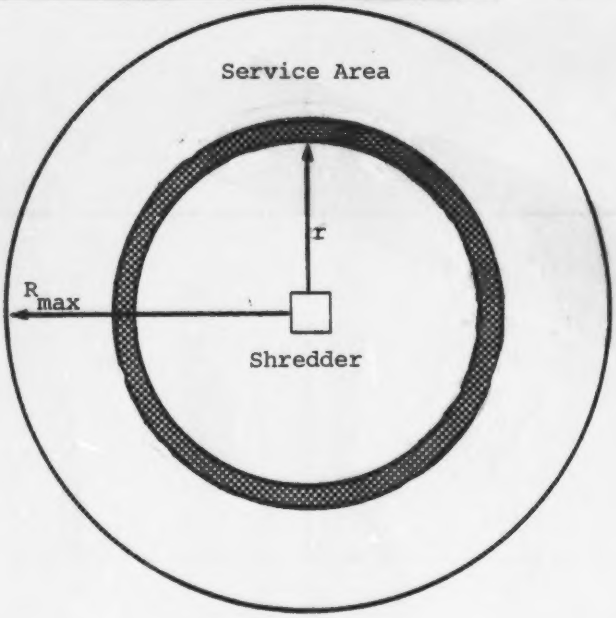
---

*More if collection costs are higher than 3-4¢/tire.

**This is the limit as dr goes to zero; $2\pi rDdr + \pi dr^2 D$ is the full derived expression.

BEGIN LAST LINE OF TEXT HERE
3/8"
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA-287 (Cin.)
(4-76)



▨ Demand Ring

	Variable Name	Typical Values (from above or text)
Value after shredding:	V	19¢/tire
Service area radius:	R_{max}	188.3 miles
Shredder unit cost:	C_S	12.5¢/tire
Transport unit cost:	C_T	.3¢/tire-mile
Floor Price:	P_o	-50¢/tire
Economies of scale (exponential):	B_1	0.8 to 1.0
Price elasticity of supply for disposal:	B_2	0.3
Tire density	D	50/mile^2
Demand normalizing factor:	α	.33*

Figure 21. Demand areas for the model.

---

*Chosen to provide 11 tires/mile^2 at a price paid to users of $-.25/tire and an elasticity of 0.3.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

1. Supply for disposal in ring (r, r + dr) = Q_r

$$= \alpha 2\pi r dr D(P_r - P_o)^{\beta_2}$$

where P_r = price at r paid by operator to generators

2. Total Supply $Q = \int_o^{R_{max}} Q_r = \int_o^{R_{max}} \alpha 2\pi r D(P_r - P_o)^{\beta_2} dr$

3. Transport Cost = $C_T r$

4. Total Processing Cost = $C_S Q^{\beta_2}$

where C_S is redefined to give the correct total cost at 800,000 tires/year, our facility base case.

Average Cost = Total Cost/Q = $C_S Q^{\beta_1 - 1}$

Marginal Cost = $\dfrac{d(\text{total cost})}{dQ} = \beta_1 C_S Q_1^{\beta_1 - 1}$

For simplicity, and to make a closed form solution possible, we assume unit returns to scale, on $\beta_1 = 1$. Then

Average Cost = Marginal Cost = C_S.

5. $P_r = V - C_S - C_T r$ (marginal cost pricing, no scale economies)

6. $P_r = P_o$ at R_{max}, which is the zero demand distance

$$R_{max} = \frac{V - P_o - C_S}{C_T} = 188.3 \text{ miles}$$

(continued)

Figure 22. Model equations.

EPA-287 (Cin.)
(4-76)

Figure 22
(continued)

7. Substituting 5 into 1,

$$Q_r = k_1 D r (k_2 - C_T r)^{\beta_2} dr$$

where $k_1 = 2\pi\alpha$

$$k_2 = V - C_S - P_o$$

8. Substituting equations 6 and 7 into equation 2:

$$Q = \int_0^{\frac{V - P_o - C_S}{C_T}} k_1 D r (k_2 - C_T r)^{\beta_2} dr$$

9. Integrating,*

$$Q = k_1 D \left[\frac{1}{C_T^{2}(\beta_2 + 2)} (k_2 - C_T r)^{\beta_2 + 2} - \frac{k_2}{C_T^{2}(\beta_2 + 1)} (k_2 - C_T r)^{\beta_2 + 1} \right]_0^{\frac{V - P_o - C_S}{C_T}}$$

10. Evaluating,**

$$Q = \frac{k_1 D k_2 (k_2)^{\beta_2 + 1}}{C_T^{2}(\beta_2 + 1)} - \frac{k_1 D (k_2)^{\beta_2 + 2}}{C_T^{2} (\beta_2 + 2)}$$

$$Q = \frac{k_1 D}{C_T^{2}(\beta_2 + 1)(\beta_2 + 2)} \left[(\beta_2 + 2) k_2^{\beta_2 + 2} - (\beta_2 + 1) k_2^{\beta_2 + 2} \right]$$

$$= \frac{k_1 D}{C_T^{2}(\beta_2 + 1)(\beta_2 + 2)} k_2^{\beta_2 + 2} \left[\beta_2 + 2 - \beta_2 - 1 \right]$$

*CRC Tables used. Can also be derived by parts.

**When $r = \frac{V - P_o - C_S}{C_T}$ the integral is 0. Thus, we are only concerned with the lower limit, where $r = 0$.

(continued)

EPA-287 (Cin.)
(4-76)

Figure 22
(continued)

11. Rearranging,

$$Q = \frac{k_1 D (k_2)^{B_2 + 2}}{C_T^2} \left(\frac{1}{(B_2 + 1)\ (B_2 + 2)} \right)$$

12. Final Result, substituting k_1 and k_2

$$Q = \frac{2\ \pi\ \alpha\ D}{C_T^2\ (B_2 + 1)\ (B_2 + 2)} (V - C_S - P_o)^{B_2 + 2}$$

EPA-287 (Cin.)
(4-76)

For our base case, numbers from Figure 21 have been substituted. They provide an estimated scale of

$$Q = 1.04 \text{ million}$$
$$\text{and } R_{max} = 188 \text{ miles,}$$

which reasonably replicates our starting point. Figure 23 graphs the tires available, the price, and the tires supplied (Qr) as a function of r. It shows, not surprisingly, that the supply rises as tires become available ($2\pi rDdr$ increases) and then drops as the effective price ($P_r - P_o$) falls. The most surprising aspect is the fast drop at the end (and, therefore, the importance of the further rings).

With a higher supply elasticity for tires entering the system, this changes. Figure 24 compares elasticities of .3, .5, .7, 1.0, and 1.5 for their effect on Q and Qr. As expected, higher elasticities lead to lower total supply, all else being equal, with the maximum collection coming from increasingly close rings: the linear increase in potential supply at each ring is quickly counteracted by the higher price elasticity, and the resulting decrease in the likelihood of gaining those tires.

It is important to note the large effect of changes in fuel price or processing cost, as demonstrated in Table 28. Here, shifts in fuel price or operating costs affect scale, as do changes in transportation cost; the shifts are similar to those found earlier, when only processing was considered. Most significant, particularly for the high elasticities, is the effect of the floor price P_o, which is interpreted as the cost to the supplier of other forms of disposal. If this cost is small, the systems become unattractive very quickly, since the sale price of the shredded tires is not very high. It is cheaper to dispose of the tires elsewhere than to pay for transport to the shredder site.

Conclusions

This analysis has investigated shredding of tires for use as fuel, first looking at the revenues and costs to the shredder operator, and then expanding the analysis to consider a simple supply function for scrap tires provided by their generators.

The first conclusion is that, given reasonable assumptions, a system can be constructed which is profitable. About half of the revenues come from sale as fuel and half from disposal charges; 75 percent of the costs are related to transportation.

Not surprisingly, the system is very sensitive to transport costs and acceptance and sale prices, but not to processing costs at least in the scale of 30 tons per day and above. This becomes even clearer when the supply side is included explicitly.

The level of collection required appears relatively low: a system covering all of New England, for example, could apparently be profitable if it received only 6 percent of the total discards, which should be achievable. While converting this analysis from a featureless circle to an actual area of

EPA-287 (Cin.)
(4-76)

Fig 23

TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE

CENTER OF PAGE

TOP OF IMAGE AREA

DROPPED HEAD; BEGIN SECTIONS HERE

HEAD; BEGIN SECTIONS HERE

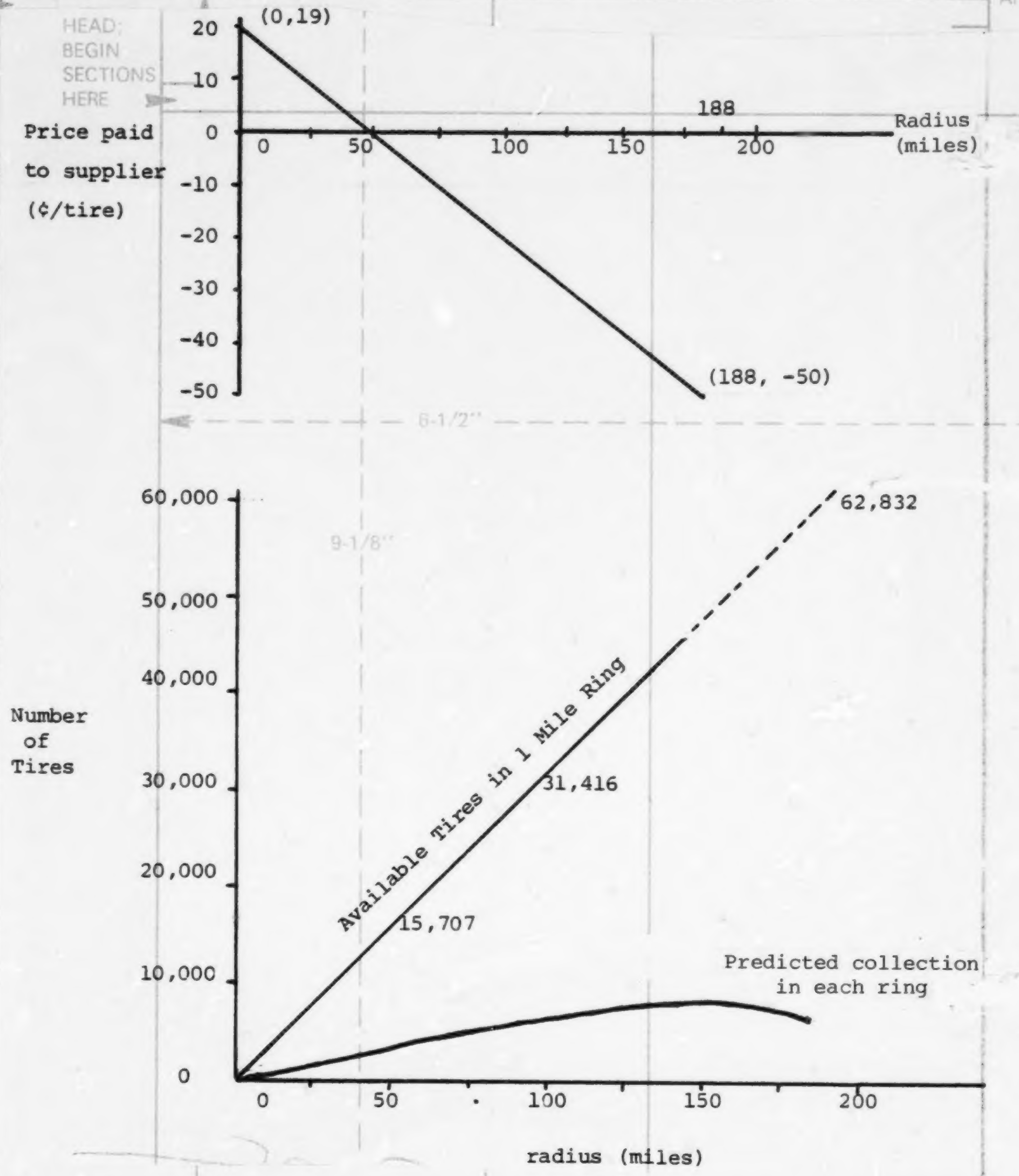


Figure 23

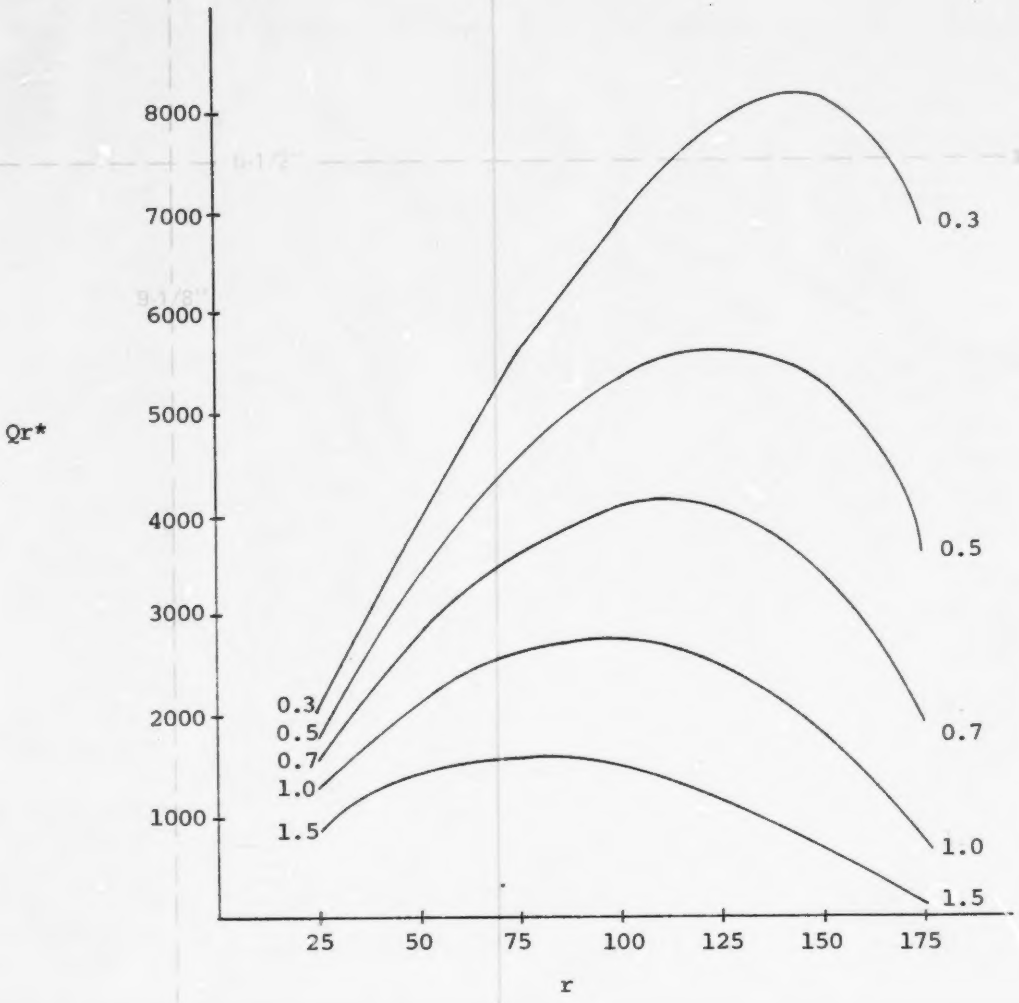
BEGIN LAST LINE OF TEXT

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

3/8"

EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
9-1/8"



*Quantity collected from a one-mile ring r miles from the shredder.

Figure 24

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 28. EFFECTS OF VALUE SHIFTS ON QUANTITY PROCESSED

Case Name	Variable Values				Q (million tires)		
	V	C_s	P_o	R_{max}	e=0.3	e=0.7	e=1.0*
Base Case	.19	.125	-.50	188	1.03	.74	.35
"New England" Fuel Price	.38	.125	-.50	252	2.01	1.62	.84
"Economies of Scale"	.19	.09	-.50	200	1.18	.87	.42
Cheaper Landfill 1	.19	.125	-.40	155	.66	.44	.20
Cheaper Landfill 2	.19	.125	-.25	105	.27	.15	.06
Free Landfill	.19	.125	0	22	.007	.002	.001
Transport Cost C_T= .002	.19	.125	-.50	232	2.32	1.67	.79

*Supply Elasticities

varying densities and convoluted transportation networks might change the results, the shift would not be great.

We make no claims for the accuracy of the various numbers used, but have attempted to include a reasonable base case and to analyze the sensitivity of the results to variations. Apparently, given a reasonable level of supply, market, and processing and transportation system, TDF can easily be profitable. It is particularly sensitive to transport costs and to the pickup and sale prices, and somewhat sensitive to the density of scrap tires and the costs of processing.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

COSTS OF ASPHALT-RUBBER TREATMENTS

Since the first experiments with asphalt-rubber formulations in 1967, a number of possible uses have been proposed for these materials. The three major applications to date are:

- seal coat
- stress-absorbing membrane interlayer (SAMI)
- crack filler/sealer.

Asphalt-rubber formulations are more expensive than conventional substitues.* An asphalt-rubber seal coat, for example, may cost about twice as much as a conventional high-quality seal coat. Given this cost relationship, use of an asphalt-rubber formualtion can be justified only if:

- its durability compensates for the increased cost;
- its performance is otherwise so superior that there is no conventional substitute (see discussion of crack sealers);
- its inclusion in a road treatment materials than would otherwise be the case, with equivalent durability and performance.

Conclusive and comprehensive dtat proving the advantages of asphalt-rubber materials is lacking, though the demonstration programs currently being supervised by the Federal Highway Administration will provide some data.** The research program being carried out by the Arizona Department of Transportation, and other experiemental efforts, may also help. The following sections review the performance benefits that would be required of these asphalt-rubber formulations if their use is to be considered cost-effective, given current costs.

Performance

Interlayer--

Table 29 shows the current cost of two recommended asphalt-rubber interlayer treatments. The cost of the interlayer ($.85/square yard) is equivalent to the cost of an additional .7 inch of conventional overlay. For any interlayer cost, Figure 25 indicates the number of inches of conventional overlay the interlayer must substitute for to make its use cost-effective.

---

*In some cases, it is difficult to identify the conventional substitute for asphalt-rubber. For example, it is claimed that an asphalt-rubber interlayer (½ inch) plus a two-inch overlay of asphalt concrete effectively substitutes for a full seven-inch asphalt concrete overlay. The cost companion is highly dependent on whether the equivalen substitue is, for example, 4, 7 or 9 inches, and there is little useful data as yet. Thus, many of the cost comparisons are problematic.

**Discussed in detail in Section 4.

TABLE 29. COST OF ASPHALT-RUBBER INTERLAYER TREATMENTS COMPARED TO COMPARED TO CONVENTIONAL OVERLAY

	Asphalt-Rubber Interlayer Cost	Overlay Thickness	Cost	Total Treatment Cost	Equivalent Inches of Conventional Overlay
Treatment I	.85	2"	2.35	3.20	2.7"
Treatment II	.85	4"	4.80	5.65	4.7"

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

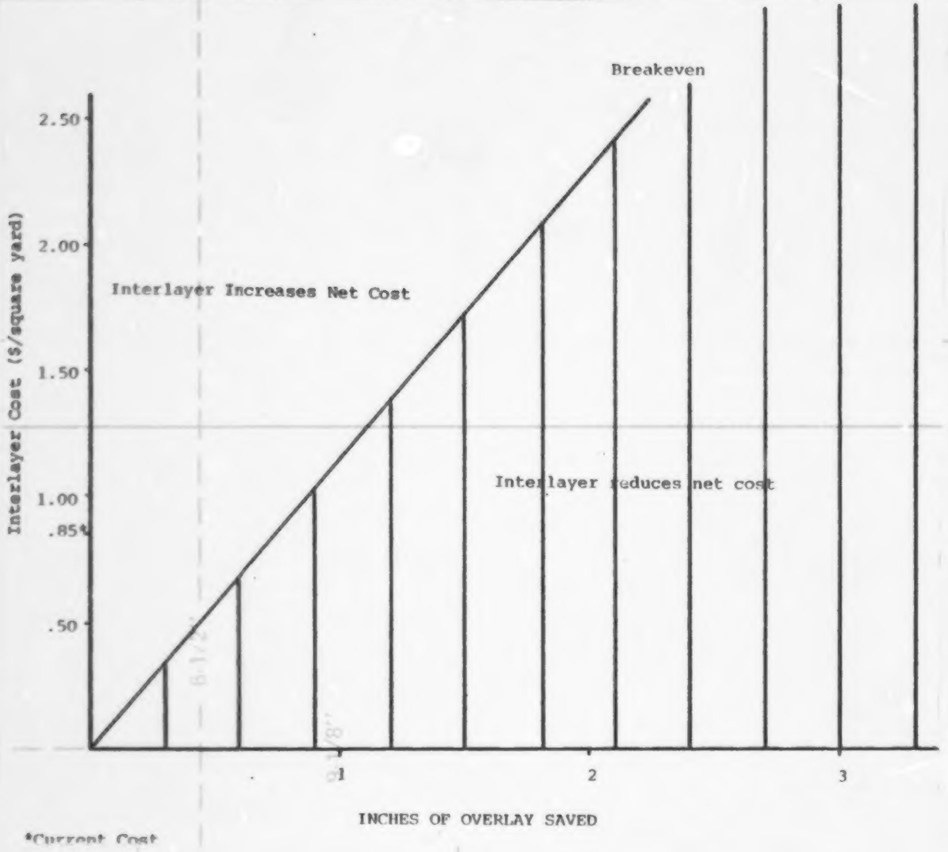


Figure 25. Breakeven performance for asphalt-rubber interlayers.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Footnote on [illegible] X Page

Treatment I (asphalt-rubber interlayer plus two inches of asphalt overlay) is, according to Sahuaro Petroleum and Aspahlt Comapny, equivalent in durability to a seven-inch overlay. Because there is as yet insufficient evidence to support this claim, it is important to compare the costs of pavement treatments using equivalent overlay thicknesses, one of which incorporates an asphalt-rubber interlayer.

The discounted payback period for the additional investment ($.85/square yard) is shown in Table 30, based on a range of possible maintenance cost savings attributable to the use of the interlayer.

A test completed in 1976 (103) revealed that a payment treatment consisting of two inches of overlay with an interlayer resulted in average annual maintenance cost savings (after three years) of $.26/square yard, compared to a two-inch overlay without the interlayer. Unfortunately, the Arizona Department of Transportation terminated its study at the end of three years, so it is unclear whether similar savings can be expected over the longer periods to recover the investment. The test does indicate the magnitude of probable savings associated with the use of the interlayer under certain conditions.

Given the added cost and uncertainty associated with asphalt-rubber formulations, many highway departments would probably expect a short payback (three to four years)*. This type of payback, given current cost relationships, would require savings exceeding those noted by the State of Arizona. A long-term study of maintenance cost savings associated with various pavement treatments would be a useful indicator of the potential benefits of asphalt rubber treatments.

Seal Coats--

Table 31 indicates that an asphalt-rubber seal coat is equivalent in cost to about an inch of conventional asphalt overlay, and about 70% more costly than a conventional seal coat. An asphalt-rubber seal coat can be cost-effective if it substitutes for a sufficient thickness of asphalt concrete overlay. This relationship between seal coat cost and overlay replaced is shown in Figure 26.

It has been suggested that an asphalt-rubber seal coat is an "effective alternate to a major overlay or reconstruction." This type of claim is not usually made for a conventional seal coat, which is generally considered to be a useful and inexpensive temporary expedient to prevent further pavement deterioration. Figure 26 indicates that an asphalt-rubber seal coat is,

---

*They certainly would expect a payback within the normal expected life of the overlay alone. A two-inch overlay has a life expectancy of about two years, and many highway departments assume that each 0.1 foot of overlay is equivalent to one year of pavement lifetime.

TABLE 30. DISCOUNTED PAYBACK PERIODS FOR AN ASPHALT-RUBBER INTERLAYER (years)

Discount Rate \ Annual Maintenance Savings (Cents Per Yard)	.10	.15	.20	.25	.30	.40
6%	13	7	5	4	4	3
10	20	9	6	5	4	3
15	>50	14	8	6	4	3
20	>50	>50	11	7	5	3
25	> 50	>50	>50	9	6	4

TABLE 31. COST OF SEAL COATS RELATIVE TO ASPHALT OVERLAYS

	Cost	Equivalent Inches of Conventional Overlay ($1.15/inch)
Asphalt-Rubber Seal Coats	$1.10	.96
Conventional Seal Coats	$0.65	.57

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
6-1/2"
9-1/8"
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

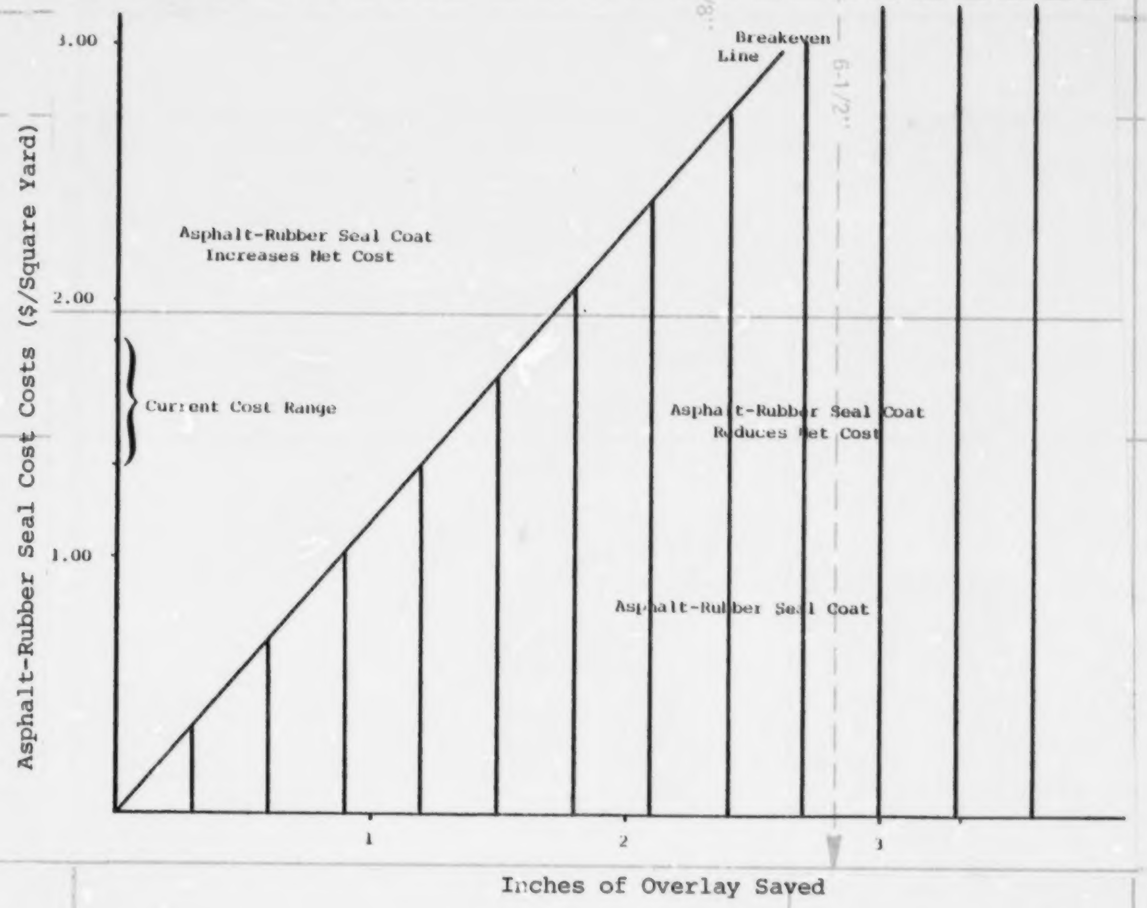


Figure 26. Breakeven performance for asphalt-rubber seal coats.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
/8"
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

at current costs, cheaper than any significant overlay. If the mean time to failure of the asphalt-rubber seal coats is equally long, use of the seal coat is recommended. However, as with interlayers, the range of substitutability of asphalt-rubber for an overlay is not well known.

An asphalt-rubber seal coat costs about $.45/square yard more than a conventional seal coat. The discounted payback periods for this investment, assuming various annual maintenance cost savings, are given in Table 32. Because of the short life expectancy of a chip seal, one would expect to recover this additional outlay in a short time span (one to two years). For maintenance cost savings equal to or greater than those found in the Arizona experiments with overlay/interlayer treatments,* however, a discounted payback period of two to three years is found. Use of asphalt-rubber seal coats to replace overlays will be cost effective if they provide equal performance, but it is not clear that the rubberized seal coats can economically replace conventional chip seals. Essentially, the asphalt-rubber seal coats are an intermediate product with costs (and probably performance) between those of these two conventional methods.

Crack Sealers--

6-1/2"

The effectiveness of crack sealing compounds is considerably easier to evaluate than interlayers or seal coats. Whereas evaluation of the cracking and pavement deterioration occurring over the life of the latter two treatments requires special data collection and processing techniques, such as an optical grid system, it is reasonably obvious if a sealing compound has failed to hold its place in a known pavement crack.

Anecdotal evidence suggests that it is not unusual for a conventional crack sealer to fail within the first year of application. On the other hand, it has been suggested that asphalt-rubber crack sealers may last several years, a performance for which there may effectively be no conventional substitute.

Asphalt-rubber crack sealers are available in premixed form (asphalt already mixed with rubber), or unmixed batches (essentially granulated rubber) designed to be mixed with asphalt at the job site. The former are extraordinarily expensive relative to high-quality conventional crack sealers, requiring an additional investment of $10.64/100 linear feet.** Prepackaged sealers are therefore only suitable for infrequent, small-volume or other special applications, such as in very remote sites.

---

*These experiments, although they did not deal specifically with seal coats, provide the best available indication under controlled circumstances of approximate maintenance costs for a variety of road surfaces.

**The current price of the conventional sealer is about $3.74/100 linear feet.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
9-1/8"

TABLE 32. DISCOUNT PAYBACK PERIODS FOR AN ASPHALT-RUBBER SEAL COAT (years)

Discount Rate \ Annual Maintenance Savings (Cents Per Square Yard)	.10	.15	.20	.25	.30	.40
6%	6	4	3	2	2	2
10	7	4	3	2	2	2
15	8	5	3	3	2	2
20	13	5	4	3	2	2
25	>50	7	4	3	3	2

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

The additional investment required for an asphalt-rubber crack sealer (as opposed to a high-quality conventional seal) mixed at the job site is $1.11/100 linear feet. The discounted payback periods for this additional investment, based on different assumed maintenance cost savings, are shown in Table 33.

The initial cost of this asphalt-rubber crack sealer is only about 30 percent more than the high-quality conventional alternative, so that the premium required of the asphalt-rubber formulation is not that great. As indicated in Table 34, the breakeven cost ratio of asphalt-rubber crack sealers relative to conventional crack sealers is higher than the current cost ratio, if it is assumed that:

- o annual treatment with the conventional crack sealer is required, and
- o asphalt-rubber crack sealers last at least 1½ years.

In general, for virtually any performance time frame, failure of the conventional crack sealer combined with satisfactory performance of the asphalt-rubber sealer over that same period would warrant selection of the latter.

Asphalt-Rubber Production Costs and Sales Prices

Previous sections have been concerned with the costs of asphalt-rubber to the end user, i.e., the highway departments at various levels of government. These users are only willing to pay a premium for asphalt-rubber interlayers, seal coats, or crack sealers if these materials can be shown to result in a sufficiently superior performance.

Although there is little empirical evidence to support the claims of asphalt-rubber proponents for the product relative to conventional alternatives, the two manufacturers of asphalt-rubber continue to market the products, and have active research and development programs. The participation of Sahuaro in this market since 1968 indicates the probably profitability of this line of business, although the company does have other revenues which it can allocate to this purpose.

Table 35 shows, for Sahuaro and the Arizona Refining Company, the most probable current production costs per gallon, including materials, the cost of the labor and equipment supplied by the companies to the customers, and a reasonable provision for profit. The calculations in Table 35 take account of the difference in the two company's formualtions, as well as their different cost of rubber inputs. Although the contract price to the customer will also reflect some portion of administrative overhead expenses, it has not been possible to reconstruct those costs here. Nevertheless, based on the difference between production price and current contract prices as shown in Table 35, we conclude that both companies are producing asphalt-rubber formulations profitably, and probably generating funds for additional research and development.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA. OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 33. DISCOUNTED PAYBACK PERIODS FOR AN ASPHALT-RUBBER CRACK SEALER MIXED AT JOB SITE

Discount Rate \ Annual Maintenance Savings (Cents Per 100 Linear Feet)	.25	.50	.75	1.00	1.25	1.50
6 %	6	3	2	2	1	1
10	7	3	2	2	1	1
15	8	3	2	2	1	1
20	12	4	2	2	2	1
25	>50	4	2	2	2	1

TABLE 34. BREAKEVEN COSTS* OF ASPHALT-RUBBER CRACK SEALERS RELATIVE TO CONVENTIONAL CRACK SEALERS (RATIO)

Durability of Asphalt-Rubber Crack Sealer (Years)	Discount Rate 6%	10%	15%	20%	25%
1	1.00	1.00	1.00	1.00	1.00
1.5**	1.47	1.45	1.43	1.42	1.40
2	1.94	1.91	1.87	1.83	1.80
3	2.83	2.74	2.63	2.53	2.44
4	3.67	3.49	3.28	3.11	2.95
5	4.47	4.17	3.86	3.59	3.36

*This analysis assumes annual treatment with a conventional crack sealer.

**For example, assume the conventional crack sealer lasted 1 year and cost \$3.74/100 feet; asphalt-rubber lasted 1.5 years and cost \$4.85/100 feet; 10% discount rate. Then the actual cost ratio $\left(\frac{4.85}{3.74} \text{ or } 1.29\right)$ is less than the tabulated ratio (1.45) so asphalt rubber is superior.

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 35. PRODUCTION COSTS FOR ASPHALT-RUBBER SEAL COATS AND INTERLAYERS

	Sahuaro	ARCO
Cost of Rubber Per Gallon of Mixture*	.15-.34	.44
Cost of Asphalt Per Gallon of Mixture**	.25	.27
Labor and Equipment	.08-.20	.08-.20
Overhead and Administration	NA	NA
Profit+	.05-.14	.09-.10
Production Price Per Gallon	.53-.93	.88-1.01

(Current Contract Prices Per Gallon, Including Freight: 1.35-1.83)

---

*Based on current prices.

**Both companies generally produce their asphalt-rubber seal coats and interlayers on-site, acting as a subcontractor to a paving contractor. Their labor and equipment costs should be similar to those experienced by these contractors. Those costs given above are based on the Van Nostrand Reinhold Company 1978 Heavy Construction Cost Files Unit Prices. The category used was 'Surface Treatments'.

+11% before taxes. Based on Business Conditions Digest (August, 1979) "Profits (After Taxes) Per Dollar of Sales, All Manufacturing Corporations". This figure was 5.4 for 1978 and the tax rate was assumed to be 49%.

- Asphalt-rubber interlayers have a cost equivalent to about .7 inch of asphalt concrete overlay;
- The substitutability of an interlayer for any thickness of overlay has not been conclusively demonstrated;
- The annual maintenance cost savings required for a three to four year payback of the interlayer investment are $.30 to $.40 square yard at a 10% discount rate;
- A two-year discounted payback (at a 10% discount rate) for a seal coat requires annual maintenance savings of $.25/square yard;
- Prepackaged asphalt-rubber crack sealers are not cost-effective, except under very special situations.
- Careful consideration should be given to asphalt-rubber crack sealers designed to be mixed at the job site, as they appear likely to be cost-effective in many applications, particularly where repeated use of conventional crack sealers would be required.

SECTION 6

PUBLIC POLICY OPTIONS AND RECOMMENDATIONS

GOALS FOR PUBLIC POLICY

Currently, over 3 million tons of passenger and truck tires are disposed on land each year: less than 800,000 tons are consumed by the various resource and energy recovery processes. Environmentally unsound land disposal practices are common, resulting in health and safety risks as well as visual pollution.

The Congress acknowledged these problems in Section 8002(h) of the Resource Conservation and Recovery Act, calling for a study of the collection, disposal and resource recovery options for scrap tires.

The first five sections of this report focused on the scope and nature of the problem, and on the technical options for resource recovery. This chapter addresses what can be done to alter the status quo and reduce the social costs of waste tires. It is also concerned with the role of the government in the tire market, realizing that there are bound to be changes in tire technology, leading to market shifts like those caused by use of steel belting and radial construction.

The first task is to identify the goals that any public program should strive to achieve. In the case of scrap tire handling, there are three goals which may be addressed jointly or separately:

- Maximize the overall benefit per unit of resource invested in passenger and truck tires, probably by increasing both new tire mileage and retreading.

- Encourage economical resource and energy recovery from scrap tires in preference to environmentally sound disposal.

- Reduce the fraction of scrap tires which are disposed of in an environmentally unsound manner.

In addition to these primary goals, there are other criteria for an acceptable public program including:

- equitable financing (in general the user of motor vehicles should pay for scrap tire disposal);

- minimal interference with private enterprise; and
- minimal administrative cost.

Public policies can include regulatory actions or economic incentives, as well as the development and testing of improved technologies. Regulations, in the form of permit procedures, disposal fees or fines, often require major enforcement efforts to be effective. The impact of economic incentives, such as tax credits or direct subsidies, is less assured, but they generally require little enforcement effort, and may have lower total administrative costs. Research and development will be the least effective option in the short term, but may offer the highest potential for long term benefits.

NO ACTION

The federal government may elect to take no specific action on the scrap tire problem. In this case, while many jurisdictions may implement local programs, the national market structure governing the generation and disposal of scrap tires will remain substantially unchanged. Holders of scrap tires, attempting to minimize the cost of disposal, will have strong incentives to bypass legitimate disposal channels, to the extent that they remain available for non-hazardous wastes.

Despite the lack of direct government action, however, the incentive structure may change dramatically as the real cost of energy increases. Private enterprise is already scrutinizing the energy and resource recovery potential of scrap tires. Sufficiently high real energy costs may result in the acceptances of scrap tires as an economically valuable item. At this point exactly how much real energy prices would have to increase to significantly change the number of tires consumed is unknown, but the analysis in Section 5 shows that some of the simpler options should be economical now.

The No Action policy would not directly address any of the three major goals. Financing of scrap tire disposal would remain with the retailer or jockey, not the tire user. No one would have a strong incentive to invest in environmentally sound disposal or marginal resource recovery systems because of the public good characteristics of the problem.

REGULATORY OPTIONS

Landfill Regulations

Under RCRA, the EPA is developing classification standards for sanitary landfills. These standards are expected to specify procedures for the environmentally sound landfilling of scrap tires and other materials. Implementation of these RCRA standards by the states is expected to result in the closing of a significant number of substandard facilities. The cost of environmentally sound disposal of scrap tires will increase as a result of both more costly handling procedures and fewer acceptable disposal sites.

The method selected for financing these additional costs is critical. There are three basic options for financing increased scrap tire disposal impacts, as discussed later in this section.

It has proven very difficult to limit improper disposal, either at known sites not meeting standards, or on property not recognized as a disposal site. Even with increased state scrutiny of disposal sites, it appears unlikely that much effort will be lavished on waste tires; hazardous wastes are a much larger issue, and tires are only hazardous in limited circumstances.

It would, at least in theory, be possible to subject tire disposal to the same cradle-to-grave regulation being applied to hazardous wastes under RCRA; this is not desirable since the social costs of improper disposal are acceptable sites, or increases in disposal cost, will lead to some divergence of the wastes to improper disposal. It becomes increasingly important to develop attractive alternatives for tire disposal, with lower costs for the jockeys and tire retailers.

Size Standards and Technology

The proliferation in tire sizes has caused considerable difficulty for retreaders, since they must invest in equipment for each new size. Changes in tire technology, particularly the introduction of the steel-belted radial, have affected both the retreading and resource recovery industries. Since new tire manufacturers have little incentive to assist these industries, it has been suggested by some that controls on new tire design could improve overall resource use. However, there is little support available for these suggestions: size proliferation in tires is at least partially a result of the rapid changes in vehicle weights and other characteristics. Regulations on tire construction would probably be counter-productive since innovations in construction types and materials provide longer mileage per tire. The only savings would come in the period where the retreaders and scrap users adjust; in the case of radials, this savings is smaller than the gain.

Tire Maintenance

One area where it has been clearly shown that there is a potential for significant improvement in resource utilization is tire maintenance. Privately-owned passenger tires are chronically under-inflated, resulting in excessive wear and side wall damage. This reduces mileage and retreadability. While direct regulation of tire maintenance is impractical, except for large fleets, tire and automobile retailers could be encouraged to provide educational information about the benefits of proper tire maintenance.

EPA-287 (Cin.)
(4-76)

ECONOMIC INCENTIVES AND OPTIONS

As discussed above, improved standards for the design and operation of sanitary landfills are expected to increase the cost of environmentally sound scrap tire disposal. If the federal government takes no action, local governments will be faced with the prospect of generating additional funds. The mechanisms used to generate the needed revenues will have differing impacts on scrap tire collection, legal and illegal disposal, and the economic feasibility of resource and energy recovery processes. It is important to carefully consider the impact of the mechanisms used to both collect and distribute funds.

Methods of Generating Revenues

There are three basic ways of raising the funds necessary for the environmentally sound disposal of scrap tires: general tax revenues, fees charged when tires reach the disposal site, and fees paid by the consumer when the tire is purchased.

It can be argued that disposal should be financed from *general tax revenues* as a government service. In many communities this is the method used to finance general solid waste collection and disposal. However, local inequities can arise since tax payments and tire generation will not be perfectly matched. Among other things, all else being equal, low income residents are less likely to invest in quality tires and will generate more tires per mile driven; on the other hand, miles driven will rise with income. The location of tire dealers will lead to an impact generally unrelated to the assessed value of their property, so the situation is confusing at best.

Disposal charges have been implemented by several communities, although revenues generally cover only a portion of the actual disposal costs. These fees have been aimed at the commercial sector, with individuals paying either a regular user charge or covered by tax payments. This approach is favored by administrators since it is simple and requires the disposer to pay. However, the scrap tire handler is not the actual user; the vehicle owner is. In communities which have imposed disposal charges, only a small percentage of scrap tires generated reach the local disposal sites. This percentage is higher in communities without such charges, and in these sites preceding the charges. The differential cannot be explained by a rapid growth in the resource and energy recovery activities in these areas; therefore, it appears that illegal disposal has increased as a result of the charges. Disposal fees lead to a better balance between services received and price paid for the commercial disposal of large numbers of tires. However, this is counterbalanced by the social cost of managing the tires which were improperly disposed. The net result appears unfavorable, based on the experiences of a few communities.

There are two types of direct user fees which could be applied: deposits and product charges. *Deposits* are a special case in which the payment collected from the consumer is returned to him when the tire is returned for reuse or disposal. Since 85 to 95 percent of discarded tires are already returned to retail outlets, a deposit system would be of little value. The product charge follows a more complex pattern: the consumer pays upon use for the later disposal. Here, the consumer would pay a product charge when purchasing the tire; the revenues from the charge would then be used to finance disposal services available at the time of discard. Thus, the funds generated must be distributed to those actually responsible for final disposal. Collection of a product charge on tires would be relatively simple, since there is already a federal excise tax of about $0.10 per pound charged to the consumer at the point of sale (and actually collected from manufacturers and retreaders).

The current excise tax on tires is paid into the Highway Trust Fund for use on transportation projects. In implementing a tire product charge, a mechanism for separating tire disposal payments from the rest of the excise tax would have to be developed. However, this would be simple if the product charge were set as a rate per pound of tire, like the excise tax.

More detailed study would be necessary to fix the appropriate rate, though rough estimates can be provided. Data from our case studies indicate a cost of $0.20 to $0.50 per tire for legal collection and disposal. This is similar to the figure derived from data by Franklin Associates, Ltd of $0.39 per tire. Given average tire weights, a product charge of 2¢ per pound would appear appropriate as a surcharge on new tires.

Distribution of Funds

If there is a disposal fee on the tires arriving at a disposal site, the collected fees simply remain within the jurisdiction running the facility. However, if general tax revenues or product charges are used to finance scrap tire disposal programs, the distribution of funds becomes a major consideration. Possible methods for distribution include bounties paid to scrap tire collectors, grants to operators of disposal sites or resource and energy recovery facilities, or support of research and development.

Bounties paid directly to scrap tire collectors would encourage scavengers to collect tires which are not currently being collected. However, these would not support environmentally-sound disposals or resource recovery efforts, except by making a larger supply available.

In special circumstances, where it is important that as many tires as possible be collected, a bounty system may prove the most effective use of public funds. For example, in La Crosse, Wisconsin, where scrap tires pose a serious public health problem, offering a bounty to residents for their tires might be helpful. Tires provide the major breeding ground for disease-carrying mosquitoes, and tires stored outside at residences are the main problem. Care must be taken in setting the terms of the bounty, of course, or it might be profitable for brokers to haul tires into the jurisdiction, defeating the purpose of the program. Bounties appear to be of value only in specialized situations.

Funds could be distributed by means of grants to acceptable disposal systems, either public or private. Grants could support the capital costs of systems, support their operation, or aid in research and development, and demonstration of new technologies.

The EPA Construction Grants Program for wastewater treatment facilities is a model of capital equipment grants program. In this case the federal government pays up to 85 percent of capital costs to construct facilities which the local authority must operate. A similar approach could be used to help communities finance the major capital expenditures for shredders to handle scrap tires. The yet to be initiated EPA program authorized under section 2004(a) of the RCRA to provide up to 5 percent of the purchase price of tire shredding equipment to either public or private operators is a program of this type.

There are already several instances where federal grants have been made for research and development efforts in the scrap tire field. One example is the grants given by the Department of Transportation and EPA to various states for asphalt-rubber demonstrations. Another is currently being run by the Department of Energy in the form of a program opportunity notice, offering support to private concerns willing to invest their own funds. This program has a strong emphasis on commercialization of technologies which have already been demonstrated on the pilot level. Grants for these purposes are one of the traditional roles of government and would potentially improve reuse of materials and energy by removing some of the "front end" costs of technology development.

While administrative costs of research development and demonstration (RD&D) are often high, and implementation often follows several years behind the programs, they are valuable when it appears that there is a high potential gain which cannot be realized with the current technologies, but could with improved systems. At present, however, our analysis suggests that the potential can be realized with current technologies; this supports a stronger effort on commercialization and reduced research and development, at least in the energy recovery area. For example, government subsidies can be used to aid investors in entering the new markets; government could preferentially contract with firms offering resource recovery, or government could enter into a technology transfer and standard-setting role. Both research into new processes and aids to commercialization of existing options appear valuable, but the current emphasis should probably be on the side of commercialization, as shown in the DOT tests, the TDF test burns in Minnesota, and the DOE program.

Finally, the funds set aside for scrap tire disposal could be distributed to qualified disposers by means of O&M grants or service contracts. The operators of any sanitary landfill or resource or energy recovery facility which takes in tires and either utilizes or disposes them in an environmentally sound fashion, could receive payment for the services provided.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Any disposer receiving payment in this manner could charge additional disposal fees, if necessary, but competition should lead to reduced direct charges to the users of the disposal service. The government would have to establish procedures for qualification of disposal firms and for audits. However, there are several models which could be used for this type of a program, such as payments made to providers of medical care and child care.

Reduced cost for adequate disposal should reduce the current economic advantage of illegal disposal. Thus, it is likely that a much greater percentage of the scrap tires would be handled in an environmentally sound manner. Such a program would also make resource and energy recovery more competitive, allowing them to grow and improve overall resource use.

Policies Without Direct Payment

There are a number of ways that the federal government could disburse funds to improve resource recovery without any direct payments being required. Tax credits for pollution control, investment in equipment, and the like, reduce tax payments from industry. The lost revenues must be replaced from somewhere, generally the sources of funds described earlier. In essence, then, tax credits and similar policies are ways of distributing funds collected by other means--subsidies in support of particular types of actions.

We have not considered such policies in great detail, but a cursory investigation supports the views presented by the Resource Conservation Committee for the more general case. We have no further recommendations on subsidies of this sort.

Recommended Approach

The most effective federal action in support of the goals discussed at the beginning of the section would be the establishment of a product charge on new tires, with the charge revenues distributed to qualified disposers based on the quantities handled. The charge should only be paid on new tires since each casing is only subject to a single disposal action. This system would be self supporting--revenues from the lost tires would easily total more than administrative costs, perhaps leaving net revenues to support RD&D--and would require that the user pay the full social cost of the tire, including its ultimate disposition.

All three of the primary goals established for any public policy can be satisfactorily addressed by:

- reducing the cost of scrap tire disposal for unacceptable casings, total cost to retreaders would be reduced, making retreads more competitive with new tires. Retreading would also receive a price advantage because the charge would only be placed on new tires.
- providing resource and energy recovery firms with the same payment as environmentally acceptable landfills, the approach

EPA-287 (Cin.)
(4-76)

provides these firms with the payment for the social service provided, without unreasonably subsidizing those which are economically unjustified;

- removing the impediment of disposal fees and thus making legitimate disposal options cost-competitive with illegitimate ones, a larger percentage of scrap tires would be disposed in an environmentally sound manner.

The government has extensive experience in the distribution of funds, and with issues such as fraud. The money details of distribution could be developed, probably using the states for site inspection and distribution to those sites.

If an average disposal cost of $0.40 is assumed for the average 22 pound tire, an appropriate product charge of $0.02 per pound (or 20 percent of the existing excise tax) would be appropriate. Since 4 million tons of tires are scrapped annually, the revenues of such a program would be approximately $40 million a year. If 5 percent of the tires were never accounted for, the $2 million in remaining funds could be used to offset administrative costs or support research, design and development.

In cases such as tire splitters, where only a portion of the scrap tire is utilized and the rest is either disposed directly or forwarded to a rubber reclaimer, payment could be based on the amount of rubber reused. In all cases, it would be up to the firm to decide if reimbursement was worth the red tape. One of the most attractive aspects of this program is that it would be voluntary and would require a minimum amount of enforcement.

A major concern in evaluating the general solid waste product charge was horizontal equity because of variations in solid waste collection and disposal costs across the country. In the case of the tire product charge, this concern is much reduced. First, we are only interested in disposal, and disposal costs are much more constant than solid waste collection costs. Payments here are also tied directly to the weight of tires received, rather than being based on population or inaccurate estimates of waste generation. Finally, it is advantageous to provide what amounts to a generally applicable price support for delivered tires, since it does not affect the incentives for local cost minimization (as would, for example, a price tied to system costs). In some cases, communities with low-cost landfill disposal would benefit from the charge system, since they would receive revenues greater than their disposal costs for tires; in other cases, communities would still have to pay local funds for a portion of disposal costs. However, this is the case currently, and a charge directly tied to the major determinant of disposal cost--weight--will not change the current distribution of costs across the country.

Vertical equity may shift, but only slightly. Given the current distribution of tire weights, quality, and prices, the poor probably use more pounds of tire per mile driven; on the other hand, they are also likely to consume more retreads, which would not be charged. Higher income households consume more miles, reducing any differences in net tire generation or charges paid. Payments, then, are likely to be distributed rather evenly across income groups.

However, current disposal costs are highest where there are concentrations of firms involved in retreading, tire sales, and distribution. To the extent that these facilities locate in poorer areas (they do) and have their solid waste disposal paid for by the poor through taxes or environmental costs of disposal on vacant lots or nearby landfills, the poor receive a burden of disposal costs greater than their share. We believe that this is the case, and that the proposed system will partially address this imbalance by reducing improper disposal and providing revenues related to quantity of tires, not assessed value of property. In any case, the burden is small: consumption is currently about one tire per capita per year, and total charges will therefore be about 40¢ per capita per year.

One possible side effect of the product charge approach would be a shift in the incentives of those handling scrap tires. Where a disposal fee is currently paid, the tire handler carefully screens tires for retreadability since it is far more profitable to sell a retreadable casing than to pay for disposal. To the extent that disposal fees are reduced, it may be less trouble to dispose of all discarded tires, eliminating the cost of inspection and hauling. However, it is felt that this potential loss of retreadable casings would be more than offset by the increase in the number of tires collected; and the fact that the value of retreadable casings would rise.

CONCLUSION

The social cost of scrap tire disposal is currently being paid indirectly, by an inefficient system. The durable tires present a serious disposal problem, and the cost of ultimate disposal should be incorporated into the cost of the new tire. Those firms currently utilizing scrap tires should receive payment for the service of tire disposal, which they are performing. This would correct market imperfections facing the tire user, the jockey, the retreader, and firms or agencies involved in resource recovery and disposal. It would reduce the large environmental burden of unsound disposal and increase the recovery of resource and energy from the 4 million tons of scrap tires discarded annually.

Therefore, it is a conclusion of this report that the most effective means of meeting public policy objectives of improved resource and energy recovery and environmentally sound disposal would be the implementation of a product charge system for the easy transfer of funds from tire users to tire disposal and resource recovery.

OK

After a careful look at the many research design and development efforts throughout this country and the world, it is a further conclusion of this study that public policy objectives would be best met by supporting projects leading to the commercialization of resource and energy technologies. Demonstration projects and matching fund capitalized equipment grants would help get the resource and energy industry mobilized to provide the disposal services needed.

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

REFERENCES

1. "Goodyear-TOSCO Rubber Recycling Plant." Journal of Commerce, p. 26, 12/24/75.
2. Environmental Science and Technology, p. 878, September 1975.
3. "Waste Tire Recycle Process." Japan Economic Journal, 16(816): 9, 8/29/78.
4. "UK Tire Recycle Plant," Financial Times, p. 9, 6/28/78.
5. "U.S. Recycled Tire Collection Campaign." New York Times, p. D9, 1/13/78.
6. "Cryogenic Process for Recycled Tires." Journal of Commerce, p. 5, 9/7/77.
7. "Recycled Waste Pyrolysis Process." Chemical Engineering, 84(18):19-20, 8/29/77.
8. "Goodyear Grants." Rubber Age, p. 68, 5/76.
9. Girdner, J. Conservation Through Retreading. Washington, DC: Tire Retreading Institute (paper delivered at 111th meeting of the Rubber Division of the American Chemical Society, May 3-6, 1977.)
10. Gentilcore, J.F., Frable, N.B., Savage, R.W. Cryogenic Grinding of Cured Rubber Scrap for Re-Use in Rubber Parts. Allentown, Pennsylvania: Air Products and Chemicals, Inc. (paper presented at 110th meeting of the Rubber Division of the American Chemical Society, October 5-8, 1976.)
11. Kazarnowicz, M.C., Osmundson, E.C., Boyle, J.R., Savage, R.W. Cryogenic Scrap Tire Processing. Allentown, Pennsylvania: Air Products and Chemicals, Inc. (paper presented at 112th meeting of the American Chemical Society, October 4-7, 1977.)
12. Yoshida, N., Ueda, T. "Thermal Decomposition Apparatus for Waste Tires." Chemical Abstracts. 88(12): 48. March 20, 1978.
13. Rogalinski, H. "Environmentally Favorable Disposal of Used Tires." Chemical Abstracts. 88(8): 223. February 20, 1978.
14. Crane, G., Kay, E.L. "Reclaiming Scrap Vulcanized Rubber." Chemical Abstracts. 86(8): 41. February 21, 1977.
15. Taggart, Jr., R.H. "Shredded Tires as an Auxiliary Fuel." Environmental Aspects of Chemical Use in Rubber Processing Operations, Conference Proceedings, (Eng.). pp. 351-70. Washington, DC: EPA

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

16. Brockers, E. "Fuel Briquets." Chemical Abstracts. 86(18):173. May 2, 1977.

17. Che, S.C., Deslate, W.D., Duraiswamy, K. "The Occidental 'Flash' Process." American Society of Mechanical Engineering Paper. 76-ENAs-42 (Eng.). 1976.

18. Winters, R.E. Recycled Rubber with Asphalt as a Membrane for Pavement Regeneration - A Progress Report. Los Angeles:Atlos Rubber, Inc. & Overflex Corporation (paper presented at 112th meeting of the American Chemical Society, October 4-7, 1977).

19. Saeki, Y., Suzuki, G. "Fluidized Thermal Cracking Process for Waste Tires, Rubber Age. 108:33-39, February 1976.

20. Gotshall, W.W., Fernandes, D.P. "New Sources of Carbon Black." Journal of Elastomers and Plastics (Eng.). 9(4):376-83. 1977.

21. Besemer, G. "Pyrolysis of Energy-Rich Industrial Wastes." Chemical Abstracts, 87(12):349. September 19, 1977.

22. Haberman, C.E. Pyrolysis of Scrap Tires Using the TOSCO II Process. TOSCO Corporation, Golden, Colorado, 1977.

23. Huff, B.J. Rubber in Asphalt Pavements. A Method for Utilizing All of Our Rubber Waste. U.S. Rubber Reclaiming Company, Inc. Vicksburg, Mississippi, 1977.

24. Plunkett, D. "Disposing of Scrap Tires." Rubber World. pp. 61-64, September 1975.

25. Bebb, R.L. "Chemistry of Rubber - Processing and Disposal." Environmental Health Perspectives, 17:101-102, October 1976.

26. "Scrap Tires Are Finding a New Home." Rubber World, p. 67, October 1978.

27. Anderson, E.V. "Economics Are Bugaboo in Scrap Tire Recycling," Chemical Engineering News. pp. 8-10, August 14, 1972.

28. Andrews, P. "Tire Shredding Economics at a Sanitary Landfill," Public Works. pp. 96-7, May 1977

29. "Reinforced Concrete." Chemical Abstracts, 87(14):225. October 3, 1977.

30. Mitsui, S. et al. "Dry Distillation of Rubber." Chemical Abstracts, 87(27):53. December 26, 1977.

31. Yoshida, N., Ueno, M., Tsuru, Y. "Treatment of Waste Tires with Microwave and Steam." Chemical Abstracts, 87(27):51. December 26, 1977.

EPA-287 (Cin.)
(4-76)

32. "Scrap Tires Can Yield Marketable Products." Environmental Science and Technology, 7(3):188-190, March 1973.

33. "New York Thruway Gets Rubber Road," The American City and County, May 1978.

34. Excerpt from article, Elastomerics, March 1978, pp. 28, 30.

35. European Chemical News, p. 27, 7/14/78.

36. "New Design, Technology Change the Tire Market." Modern Plastics, p. 70 September 1978.

37. Buchanan, C.C., "A Comparison of Sport Fishing Statistics from Man-Made and Natural Habitats in the New York Bight." National Marine Fisheries Service, Sandy Hook Marine Laboratory, Highlands, New Jersey.

38. Buchanan, C.C., "Effects of an Artificial Habitat on the Marine Sport Fishery and Economy of Murrells Inlet, South Carolina," p. 15, Marine Fisheries Review. 35(9):1973.

39. Dzimian, R.J. "Hot-Poured Sealants." U.S. Rubber Reclaiming Co., (paper presented at 49th Annual Meeting of the Highway Research Board, 1970).

40. "Cryogenic Process Recycles Used Auto Tires." Chemical & Engineering News, June 17, 1974.

41. "Tormented Scrap Rubber Tires Make Ideal Soil Conditioner." NBS Microwaves, February 1974.

42. Schormeier, R. and McDonald, C.H., "Summary of Observations and Recommendations that Revolved from the Pavement Inspection and Evaluation in August 1976 of the Asphalt-Rubber Seals in the General Phoenix Area."

43. Lansdon, H.G., "The Blending of Granulated Rubber and Asphalt for Use as a Crack Sealant." Arizona Department of Transportation.

44. Morris, G.R. and McDonald, C.H. Asphalt-Rubber Alters Absorbing Membranes. Field Performance and State-of-the-Art. Arizona Department of Transportation (app. 1975).

45. Green, E.L. and Tolonen, W.J. The Chemical and Physical Properties of Asphalt-Rubber Mixtures. Arizona Department of Transportation, July 1977.

46. Westerman, R.R. Tires: Decreasing Solid Wastes and Manufacturing Throughput. EPA-600/578-009, July 1978.

47. Wolk, R.H. and Battista, C.A. "Study of the Technical and Economic Feasibility of a Hydrogenation Process for Utilization of Waste Rubber." Solid Waste Research Laboratory, U.S. EPA, August 25, 1972.

48. Kelly, Michael. "Old Car Tires Help Steelmakers Fight Slag," The Plain Dealer, Cleveland, Ohio, August 14, 1974.

49. Richardson, H.M. "Forecasting in the Rubber Industry," CMRA, New York City, May 1974.

50. Green, C.E. "A Study of Methods for Disposal of Scrap Rubber Tires." Technical Report No. 11748, U.S. Army Tank Automotive Command, April 1973.

51. Koval, F.J. Tire Technology. The Goodyear Tire and Rubber Co. 1973.

52. Crane, G., Elefritz, R.A., Kay, E.L., Laman, J.R. "Scrap Tire Disposal Procedures," Rubber Chemistry and Technology, 51:577-599, 1978.

53. Myatt, D.O. Developments in Mechanizing Tire Unit Fabrication for Fish Havens. South Carolina Wildlife and Marine Resources Department, Charleston, South Carolina, 1977.

54. Ross, N.W. Floating Breakwaters. University of Rhode Island, Narragansett, Rhode Island, 1977.

55. Candle, R.D. Scrap Tire Highway Impact Barriers. The Goodyear Tire and Rubber Company, Akron, Ohio. 1977.

56. American Chemical Society, Division of Rubber Chemistry, Library and Information Services. Disposal and Reuse of Waste Rubber, Bibliography Number 136. January 1975.

57. Albrecht, Oscar. "Shipping Wastes to Useful Places." Environmental Science and Technology 19(5): 440-442, May 1976.

58. Anonymous. "Vermont Repairs Section of Faulty I-89." New England Construction. November 15, 1976. p. 23.

59 Anonymous. "1976 will be a Banner Year for the Tire Industry." Rubber World. October 1976, p. 12.

60. Anonymous. "1976: America's Year of the Radial." Special Report, Rubber World, April 1976.

61. Beckman, J.A., G. Crane, E.L. Kay, and J.R. Laman. "Scrap Tire Disposal" Rubber Chemistry and Technology 47(3): 597-624, July 1974.

62. Brand, B. (Battelle Columbus). Scrap Tire Utilization in Road Dressings, EPA 670-2-74-014, March 1974.

63. Broton, N.R. "Cryogenic Recycling of Solid Waste." Public Works 107(9): 84-85. September 1976.

64. Cleary, T.M., and W.H. Clark, III. "Old Tires Contribute to Thruway Maintenance." Public Works Magazine. July 1973.

65. Collins, L.W., W.R. Downs, E.K. Gibson, and G.W. Moore. An Evaluation: The Potential of Discarded Tires as a Source of Fuel, National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas. December 1974. 17pp NASA-TM-X-58143, JSC-09243, N75-1513/OWP.

66. Colugna, L. and R. Stone (eds.). Proceedings of an International Conference on Artificial Reefs. NOAA-75-2009. March 1974.

67. Cox, R.G. "NTRDA Marketing Guidelines -- 1977" NTRDA Dealer News. November 22, 1976, 39(33):entire issue.

68. Cox, William L. "Recycle and Reuse of Tires." SME Technical Paper EM74-225, Society of Manufacturing Engineers, 1974.

69. Crane, G. and E.L. Kay. "Scrap Tire Disposal Process,", and Crane, G., J.W. Fieldhouse, and E.L. Kay. "Antioxidant Activity of Depolymerized Scrap Rubber," Rubber Chemistry and Technology. 48(1):50-61 and 62-68, 1975.

70. Office of Solid Waste Management Planning. Decision-Makers Guide in Solid Waste Management. EPA, 1976, SW-500.

71. U.S. Environmental Protection Agency, Office of Solid Waste Management Programs. Second Report to Congress on Resource Recovery and Source Reduction, Report SW-122, EPA, 1974.

72. U.S. Environmental Protection Agency, Office of Solid Waste Management Programs. Third Report to Congress on Resource Recovery and Source Reduction, Report SW-161, EPA, 1975.

73. EPA Development Document of Effluent Limitations Guidelines and New Source Performance Standards for the Fabricated and Reclaimed Rubber Segment of the Rubber Processing Point Source Category. Washington, DC, 1974.

74. Frable, N.B. "Cryogenic Grinding Saves $$, Recycled Scrap Becomes Valuable Resource." Rubber World. October 1976. pp. 66, 68, and 87.

75. General Services Administration, Federal Supply Service. Federal Motor Vehicle Fleet Report for Fiscal Year Ending June 30, 1975. FPMR 101-38.1, July 1976.

76. Goddard, H.C. An Economic Evaluation of Technical Systems for Scrap Recycling. EPA 600/5-75-019, December 1975.

77. Hedley, W.H., T.E. Ctvrntnicek, W.J. Search. Disposal Study: Tires and Other Polymeric Materials. Monsanto Research Corp. for Army Natick Development Center, April 1975. Contract DAAK03-74-C-0136.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

78. Howarth, J.T., J.A. Carter, and K.R. Sidman (Arthur D. Little, Inc.). Economic Analysis of Effluent Guidelines: Rubber Processing Industry. EPA-230-2-74-024. August 1974.

79. Humpstone, C.C., E. Ayers, S.G. Kearney, and T. Schell. Tire Recycling and Reuse Alternatives. IRT for EPA, 1974.

80. Kowalski, T., and N. Ross. How to Build a Floating Scrap Tire Breakwater. NOAA-76-20901, 1975.

81. LaGrone, B.D. and Huff, B.J. "Utilization of Waste Rubber to Improve Highway Performance and Durability" (paper presented at the 52nd Annual Meeting of the Highway Research Board, January 1973).

82. LaGrone, B.D. and Huff, B.J. "Use of Waste Rubber in Asphalt Paving" (paper presented at the Colorado State University Asphalt Paving Seminar, December 1973).

83. Larsen, J.W. and B. Chang. "Conversion of Scrap Tires by Pyrolysis in Molten Salts." Rubber Chemistry and Technology. 49(4):1120-1127. September - October, 1976.

84. Lowe, R.A. "Summary of Tire Retreading Industry." EPA Internal Memo, 1/15/73.

85. McDonald, C.H. "An Elastomer Solution for Alligator Pattern, or Fatigue, Cracking in Asphalt Pavements." Presented to the International Symposium on the Use of Rubber in Asphalt Pavements. May 1971.

86. Moats, E.R. "Goodyear Tire-Fired Boiler," Resource Recovery and Conservation, 1(1976) 315.

87. National Highway Transportation Safety Administration. Federal Motor Vehicle Safety Standards, Part 571; #109, #117, #119.

88. Ochs, G.L. and K.C. Coram. Scrap Tire Disposal and Utilization Alternatives: A State-of-the-Art Report. Franklin Institute, 1975.

89. Olsen, R.E. Rubber-Asphalt Binder for Seal Coat Construction. Implementation Package 73-1, Office of Development, FHWA, February 1973.

90. Pettigrew, R.J., F.H. Roninger, W.J. Markiewicz, and M.J. Gransby. Rubber Reuse and Solid Waste Management, EPA, 1971 (SW-22c).

91. Rubber Manufacturers Association, Management Information Services. Rubber Industry Facts. RMA, 1901 Pennsylvania Av., N.W., Washington, DC. 20006, October 1975. (with handwritten updates and statistical reports on 1977 forecasts and a monthly report for December 1975.)

92. Packet of press releases and articles received from the Rubber Manufacturers Association, December 3, 1976.

93. Scott, John A., A Feasibility Study of Cold Process Retreading and Its Adaptability to the Army Maintenance Program. Army Material Command Texarkana Texas Intern Training Center. Report Number USAMC-ITC-2-73-21. March 1973.

94. Smithers Scientific Services, Inc. A Study of the Feasibility of Requiring the Federal Government to Use Retread Tires. Prepared for EPA-OSWMP, 1974.

95. Stephens, J.E. and S.A. Mokrzewski. "The Effect of Reclaimed Rubber on Bituminous Paving Mixture." Civil Engineering Department, University of Connecticut. Report CE74-75. March 1974.

96. Stern, K.M. (Gordian Associates). "Rubber Industry and the Environment" Rubber World, December 1973. pp. 53-54.

97. Stirbling, J.B. "Cyclone Furnaces", Engineering. October 1972.

98. Stone, R.B., C.C. Buchanan, and F.W. Steimle, Jr. Scrap Tires as Artificial Reefs. Report SW-119, USEPA, 1974.

99. Taggart, R.H., Jr. "Shredded Tires as an Auxiliary Fuel." Environmental Activities Staff, General Motors Technical Center, 1975.

100. Tire Retreading Institute. Retreading Radial Passenger Tires. Washington, DC:TRI, April 1976. (1343 L Street, Washington, DC 20005--$2.50.)

101. Wagner, E.J. "Retreadonomics." Retreader's Journal 20(5):3-9, May 1976.

102. Wagner, E.J. "1976 Retread Industry Forecast." Retreader's Journal 19(12):3-5, December 1975. (Produced by Retreading Consultant Services Inc., Louisville, Kentucky.)

103. Way, George. Prevention of Reflective Cracking in Arizona Minnetonka-East. Prepared for U.S. Department of Transportation, ADOT Report #1, HPR-1-13(224).

104. Schulman, B.L. and P.A. White. "Pyrolysis of Scrap Tires Using the TOSCO II Process--A Progress Report." Reprint from the ACS Symposium Series, #76, Solid Wastes and Residues, 1978.

105. Westerman, R.R. "Waste Management Through Product Design: The Case of Automobile Tires." in OSWMP (ed.) Proceedings: 1975 Conference on Waste Reduction. SW-7p. U.S. EPA, 1975.

Sears, J.W. "Retreading and the 100,000 Mile Tire." in OSWMP (ed.) Proceedings: 1975 Conference on Waste Reduction. SW-7p. U.S. EPA, 1975.

Snyder, R.H. "Memo Re Westerman's Thesis." Uniroyal, Inc. 3/21/75.

EPA-287 (Cin.)
(4-76)

106. Roy F. Weston, Inc. *A Systems and Methods Analysis of the Reuse of Consumer Rubber Goods*. Rubber Manufacturer's Association, October 1971.

107. Roy F. Weston, Inc. *Development Document of Effluent Limitations Guidelines and New Source Performance Standards for the Tire and Synthetic Segment of the Rubber Processing Point Source Category*. Washington:EPA, 1974.

108. Wolfson, D.E., J.A. Beckman, J.G. Walters, and D.J. Bennett. *Destructive Distillation of Scrap Tires*. Bureau of Mines Report of Investigations #7302, September 1969.

109. Beckman, J.A., G. Crane, E.L. Kay, and J.R. Laman. *The Destructive Distillation of Used Tires in a Continuous Pilot Plant*. Firestone, April 1972. (Presented at the Spring meeting of the Akron rubber group.)

110. Beckman, J.A., G. Crane, E.L. Kay, and J.R. Laman. "Destructive Distillation," *Rubber Age*, April 1973, pp. 43-48.

111. Schlesinger, M.D., W.S. Sanner, D.E. Wolfson. "Pyrolysis of Waste Materials from Urban and Rural Sources." *Third Mineral Waste Symposium*, 1972.

112. *Public Works*, May 1974.

113. *Reuse/Recycle*, October 1974.

114. *Reuse/Recycle*, October 1976.

115. J.G. Del Gatto. "Bandag Retreads: A Gripping Story." *Rubber World*, November 1973.

116. *Rubber World*, July 1974.

117. *Rubber World*, August 1974.

118. "N.H. Utility to Burn Old Tires in a Blend with Coal," *The Energy Daily*, September 7, 1978.

119. Search, W.J. and Ctvrtnicek, T.E. "Resource Recovery Systems for Non-Recappable Rubber Tires," *Resource Recovery and Conservation* 2 (1976).

120. Resource Planning Associates, Inc. "Energy Conservation Through More Efficient Use of Waste Tires," Washington, DC, May 1977.

121. Thomas, W.B. "Disposal and Use of Scrap Tires," Big "O" Tire Company Oakland, CA.

122. Snyder, R.H., Vincent, V.R., and Querry, F.C. "Scrap Tire Carcass Disposal." Uniroyal Tire Company, Detroit, MI.

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

123. Brooks, Lester. "Brain Power Is Saving Energy." American Way. October 1978.

124. Adler, P.W., Thomas, P.O., and Sekhar, B.C. A Study on Competition Between Natural and Synthetic Rubber, Malaysian Rubber Research and Development Board, Kuala Lumpur.

125. Purcell, A.H. "Waste Rubber," NCRR Bulletin, Winter 1974.

126. Purcell, A.H. "Future Supply Factors for Retreadable Tires: An Overview and Suggested Action Plan." Report to the National Tire Dealers and Retreaders Association, August 1977.

127. Rhoten, Claudia. "Scrap Tire Processing and Disposal Program," presented at the National Tire Disposal Symposium, June 1977.

128. Purcell, A.H. "Waste Tires and Their Utilization: An Investigation of Trends and Obstacles," prepared for the U.S. Department of Energy, EM-78-X-01-2979, June 1978.

129. "The Tire Scrapper." Alternative Energy Company, 1977.

130. "Tyre-maker's Treadmill." The Economist, April 15, 1978.

131. Purcell, A.H. "Tire Recycling: Research Trends and Needs," presented at the First World Recycling Congress, Basel, Switzerland, March 1978.

132. Smith, Mona F., Editor. "Solid Waste Reclamation and Recycling, Part 6, Tires." NTIS/P5-78-0766, August 1978.

133. Humpstone, Charles C., et al. "Tire Recycling and Reuse Incentives," International Research and Technology Corporation, Washington, DC, 1974.

134. "NTDRA To Unveil Computerized Solution To Retread Matrix-Match Problem," Dealer News, September 18, 1978

135. "Congress Sends Carter Bill to Stop Retread Registration Requirement," Dealer News, October 30, 1978.

136. "Matrix Selector Fills Retreaders' Needs," Dealer News, October 30, 1978.

137. Use of Waste Materials and By-Products in Road Construction. Organisation for Economic Co-operation and Development, September 1977.

138. Westerman, Robert R. Tire Profits and Waste Management Through Retreading and 100,000 Mile Original Equipment Tires. Sacramento: California State University, paper presented at National Tire Dealers Symposium, June 14 and 15, 1977.

139. Strauch, Douglas L. The Used Tire Problem in California. Paper delivered to the National Tire Disposal Symposium, June 14 and 15, 1977.

140. Lansdon, H.G. The Development, Use and Potential of Asphalt-Rubber For Maintenance and Construction of Highways. Phoenix: Sahuaro Petroleum and Asphalt Co., paper presented to National Tire Disposal Symposium, June 14 and 15, 1977.

141. Butlin, John. The Management of Used Tyres--Draft Final Report. Organisation for Economic Co-operation and Development, Waste Management Policy Group, Paris, 25th October 1978.

142. Peterson, Charles. Statement Before the National Tire Disposal Symposium, June 14, 1977.

143. Beckman, J.A., Crane, G., Elefritz, R.A., Kay, E.L., and Laman, J.R. Reclamation of Scrap Tires. Akron: Firestone Tire and Rubber Co., Paper presented at National Tire Disposal Symposium, June 14 and 15, 1977.

144. Albrecht, Clinton R. Maryland's Waste Tire Program. Annapolis: Maryland Environmental Service, paper presented at National Tire Disposal Symposium, June 14 and 15, 1977.

145. Yakowitz, Harvey. The Interaction of P.L. 94-580 with Uses for Discarded Tires. U.S. Department of Commerce, paper presented at National Tire Disposal Symposium, June 14-15, 1977.

146. "Scrap Tire Pyrolysis Project Nears Completion." Polymer Paint and Colour Journal, 167(32):919. 11/16/77.

147. Kay, E.L. and Laman, J.R. A Review of Scrap Tire Disposal Processes, SAE Technical Paper Series, Publication #790301 (paper presented at exposition at Cobo Hall, Detroit, February 26-March 2, 1979).

148. Smith, Don. "The Rubber Waste Problem: Is Recycling Being Discovered?" Rubber World, December 1978, pp. 46-49.

149. Wing, Elizabeth. "Tracking Wisconsin's Most Deadly Mosquito," The Milwaukee Journal, pp. 46-51, June 13, 1976.

150. Hippler, L.A. "Evaluation of Rubberized Asphalt Crack Sealers," Idaho Transportation Department, Special Report No. ML-9-75-6, July 1, 1979.

151. Herendeen, Harry. "Evaluation of Stress Absorbing Membrane Seal in Idaho." FHWA Demonstration Projects Division, DOT-FH-15-190. December 1978.

EPA-287 (Cin.)
(4-76)

152. Lansdon, H.G. "Construction Techniques of Placement of Asphalt-Rubber Membranes." Presentation to the 13th Paving Conference, University of New Mexico, January 8-9, 1976.

153. "Spent Tire Pyrolysis May Add Bounce to Recycling." Chemical Engineering, August 2, 1976, p. 52.

154. Energy Recovery Research Group, Inc. "Potentials for Energy Recovery by Pyrolytic Conversion of Solid Carbonizable Waste Materials." December 1, 1978.

155. Sorenson, R.K. "Evaluation of Stress Absorbing Membrane Interlayer (SAMI)." Idaho Transportation Department, Construction Project I-80N-3(64)207, December 1978, Initial Report.

156. Hill, James W. "Asphalt-Rubber Crack Fillers." Idaho Transportation Department, Special Report Number ML-7-77-L, May 10, 1977.

157. Herendeen, Harry. "Evaluation of Stress-Absorbing Membrane Interlayer (SAMI) In Idaho." FHWA Demonstration Projects Division, DOT-FH-15-191, December 1978.

158. Alternative Energy Company. Resource Recovery & Recycling Program for the State of California. Sacramento, California, January 1979.

159. Anonymous, "Scrap Tires Are Finding a New Water Home." Rubber World, 67, October 1978.

160. Finney, A. "Tire Sizes: Are So Many Really Necessary?" Rubber World, 25-56, February 1979.

200. Interview with Douglas Brown, Federal Highway Administration, October 30, 1978.

201. Interview with Jack Cunningham, Alternative Energy Company, Oakland, California, November 1, 1978.

202. Interview with Philip Taft, National Tire Dealers and Retailer's Association, November 13, 1978.

203. Interview with Jerome Collins, Department of Energy, November 13, 1978.

204. Interview with David Blank, Bureau of Domestic Commerce, November 13, 1978.

205. Interview with Frank Ryan, Rubber Manufacturer's Association, November 17, 1978.

206. Interview with Art Casanova, NHTSA, November 21, 1978.

207. Interview with Troy Neisler, Warner-Robbins Air Force Base, Georgia, December 4, 1978.

208. Interview with Laverne Morgan, Office of Fleet Management, U.S. Postal Service, December 4, 1978.

209. Interview with Paul Perlsweig, Connecticut Department of Environmental Protection, December 4, 1978.

210. Interview with Mr. Lowell Stockdale, GSA, December 5, 1978.

211. Interview with W.T. (Bill) Thompson, Genstar Materials Ltd, 8955 Shaughnessy Drive, P.O. Box 2300, Vancouver, BC, V6A 36W, December 5, 1978.

212. Interview with Mr. Wright, Item Manager, Tires, Warner-Robbins Air Force Base, Georgia, December 5, 1978.

213. Interview with John Butlin, University of Manchester, Department of Agricultural Economics, Manchester, M13 9BL, England, December 12, 1978.

214. Interview with Tom Harry, Executive Vice President, General Manager, Sales & Marketing, Brad Ragan, Inc., Spruce Pine, NC, December 14, 1978.

215. Interview with Jeanne McCormick, Bureau of Refuse, Portland, Oregon, December 15, 1978.

216. Interview with John Loudis, International Baler, Jacksonville, FL, December 29, 1978.

217. Interview with Max Salkeld, Montgomery Industries, 2017 Thelma Street, Jacksonville, FL, December 28, 1978.

218. Interview with Jack Stephens, School of Engineering, University of Connecticut, January 5, 1979.

219. Interview with Joe Schultz and Bob Brown, Office of Solid Wastes, Department of Environmental Quality, State of Oregon, January 5, 1979.

220. Interview with Mel Zimelman, Refuse Energy Systems Company (RESCO), January 9, 1979.

221. Interview with Roger Hardy, Public Service Company of New Hampshire, January 10, 1979.

222. Interview with Dr. F. Cecil Brenner, NHTSA, January 10, 1979.

223. Interview with Jim Johnson of Goodyear, Akron, OH, January 11, 1979.

224. Interview with Dr. Joseph Chu, Environmental Activities Staff, General Motors Corporation, January 11, 1979.

225. Interview with Murry Baker, Ecological Energy Corporation, Allenstown, NH, January 11, 1979.

226. Interview with Dr. Stephen G. Miller, Avram Co. (representing Gould, Inc.); Christopher M. Beigle and Peter R. Bennett of Gould Inc. New Business Group, 540 E. 105th Street, Cleveland, OH, 44108, January 17, 1979.

227. Interview with Dick Kuhnau, Metropolitan Disposal Company, Portland, Oregon, January 11, 1979.

228. Notes from Transportation Research Board Annual Meeting, January 15, 1979

229. Interview with Jack Cunningham, Alternative Energy Company, Sacramento, California, January 30, 1979.

230. Interview with William Thomas, Big "O" Tire Company, Oakland, CA, January 16, 1979.

231. Interview with Merle Irvine, Metropolitan Service District, Portland, Oregon, January 23, 1979.

232. Interview with R.M. Payson, National-Standard Company (Rawls Division), February 16, 1979.

233. Interview with Gene Morris, Arizona Department of Transportation, February 1979.

234. Interview with Don Nielsen and Jim Bagley, Arizona Refining Company, Phoenix, Arizona, February 9, 1979.

235. Interview with H.G. Lansdon, P.E., Sahuaro Petroleum & Asphalt Co., Phoenix, Arizona, February 9, 1979.

236. Interview with Jerry Bennello, Denver Landfill, Denver, Colorado, February 10, 1979.

237. Interview with Paul White, Corporate Development Director, TOSCO Corp., Los Angeles, CA, February 12, 1979.

238. Interview with James Hill and Al Stanley, Idaho Transportation Department, Boise, Idaho, February 13, 1979.

239. Interview with Michael C. Kazarnowicz of Air Products and Chemicals, Inc., Allentown, Pennsylvania, March 12, 1979.

240. Interview with Joe Schiren, Landfill Supervisor, Anne Arundel County Landfill, Millersville, Maryland, March 13, 1979.

241. Interview with Parker Andrews, Chief, Anne Arundel County Solid Waste Bureau, March 13, 1979.

EPA-287 (Cin.)
(4-76)

242. Interview with Howard Beezer, Vice President, Garner Equipment Co., Washington, DC, March 13, 1979.

243. Interview with Carl Davis, Roland's Tire Service, New Bedford, MA, March 1979.

244. Interview with Jim Cozzetto, Metropolitan Disposal Company, Portland, Oregon, March 30, 1979.

245. Interview with Norm Murphy, Northwest Manager, Retronics, Inc., Portland, Oregon, March 30, 1979.

246. Interview with Merle Greenstein and Peter Rubstein, Energy Recovery Research Group, Inc., Portland, OR, March 30, 1979.

247. Interview with Don Grimshaw, Grimshaw Tire Company, Portland, Oregon, March 30, 1979.

248. Interview with Harold Lavelle, Lavelle Landfill, Portland, Oregon, March 30, 1979.

249. Interview with Paul Norr, lawyer in private practice, Portland, Oregon, March 30, 1979.

250. Interview with Steve Sanders and Bob Brown, Department of Environmental Quality, Portland, Oregon, March 30, 1979.

251. Interview with John Trout, Teamsters Local #281, Portland, Oregon, March 30, 1979.

252. Interview with Lewis Lakin, President, A. Lakin & Sons, Inc., Chicago, Illinois, March 1979.

253. Interview with Professor Thomas Tadeusz Kowalski, URI Ocean Engineering Department in Kingston, RI; and Neil Ross, Marine Advisory Specialist, Marine Advisory Service, Narragansett, Rhode Island, April 4, 1979.

254. Interview with Murry Baker, Consulting Engineer, Ecological Energy Corporation, Concord, NH, April 6, 1979.

255. Interview with Jeffrey Libman, Embassy Tire Company, Edison, NJ, May 14, 1979.

256. Interview with Dr. Carl Kappus, National Center for Disease Control, Atlanta, Georgia, August 1979.

257. Interview with Richard Buckley, President, Schiavone Tire & Rubber Recycling Company, North Haven, CT, July 1979.

258. Interview with Dr. Wayne Thompson, Wisconsin Department of Preventive Medicine, August 1979.

TYPING GUIDE SHEET
EPA-287 (Cin.)
(4-76)

259. Interview with Mr. Becker, Plant Engineer, Uniroyal, Eau Claire, Wisconsin, July 1979.

260. Interview with Office of Exporting Information, Boston, MA June 22, 1979.

261. Interview with Gene Burkett, Goodyear Tire & Rubber Company, Environmental Division, June 26, 1979.

262. Interview with James Grogan and Daryl McGlaughlin, Georgia-Pacific, Toledo, Oregon, August 20, 1979.

263. Interview with Jim Galehouse, Goodyear Burning Facility; and Mr. Slazer, Goodyear Central Office; Akron, Ohio, June 6, 1979.

264. Interview with Steve Taff, University of Wisconsin, Extension, April 10, 1979.

265. Interview with Donals Kyser, Division of Solid Waste, Minnesota pollution Control Agency, June 25, 1979 and September 24, 1979.

300a-300e. Survey Interviews with: Jim Morna, Firestone dealer; Tony Sibilia, Goodyear dealer; Don Colleton, service station owner; George Silva, service station owner; Jay Blier, retreader; Sydney Katz, retreader; Clarence Miller, retreader; Jerry O'Neil, Firestone retreader; John Botellino, tire jockey/grader; Tom Ferreria, casing grader; and Bob Feinburg, Eastern Rubber Grinders; all located in the greater Boston area, July 1979.

301a-301e. Survey interviews with: Bruce Latimer and Frank Spare, Firestone dealers; Mr. Arnold and Bob's Tire Company, Goodyear dealers; Chris Baker, General Tire dealer; Bob Ignaizzi, Goodrich dealer; Tom Dickson, service station owner; Paul Fischer, service station owner; Henry R. Kuzzinski, service station owner; James Mullin, service station owner; Rosedale Shell, service station; Mr. Clark, retreader; Paul Coberly, retreader; Carl House, retreader; Frank Liszt, Firestone retreader; Jay Rothstein, Independent Tire dealer (retreads); Uniroyal retreader; Normal Emmanuel, casing grader & shredder; and Mr. Weis, Baltimore County Refuse; all located in the greater Baltimore area, July 1979.

302a-302e. Survey interviews with: Ron Cox, Larry Matlack, and OK Tire Store Firestone dealers; Buckhead Tire Center, Gary Gage, and John Morris, Goodyear dealers; Atlanta General Tire, General Tire dealer; Charles Allen, service station owner; Mr. Bennett, service station owner; Frank Drummin, service station owner; C.J. Lewis Gulf, service station; Pierce Texaco, service station; Ray's Chevron, service station; Red Stauffer, Firestone retreader; J.J. Seiter, Bandag retreader; Mr. Boyd, retreader, Jim Otis, Firestone reclaim; Gary Anderson, Fulton County DPW; Phil Eves, Georgia DNR; Roy Jones, Cobb County Landfill; and Mr. Pruett, DeKalb County Sanitation Department; all located in the greater Atlanta area, July 1979.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
7/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

303a- Survey interviews with: Berry Tire Co., independent dealer; Bob
303g. Delelio and United TBA, Goodyear dealers; Hoppe Tire Company and The Undercarriage, Firestone dealers; Margie Niecestro, Goodrich dealer; Sherrod's Standard, service station; Three J's, service station; Wardell's Mobil, service station; Larry Cudney, retreader; Dan Tafel, Firestone retreader; Bruce Myre, Goodyear retreader; Mr. Lange, tire jockey; Bill Young, tire broker; Bill Baker and Jack Robertson, Goodyear reclaimers; Norm Chadwick, rubber grinder; Midwest Rubber Reclaim, reclaimer; Mr. Kraus, Firestone Tire "Destruction" Plant; Roy Strome, refuse hauler; Jim Galehouse, Goodyear Burning Facility; and Mr. Salzer, Goodyear Central Office; all located in the greater Chicago area, July 1979.

304a- Survey interviews with: Alexander Brothers and CFO Service Center,
304e. Goodyear dealers; Crestview Service Center, independent dealer; a Firestone dealer; Al's Texaco, service station; Bridge Ray Shell, service station; Mr. Lalo, service station owner; Jesse ______, service station owner; Ray Barrett, Firestone retreader; Larry Dady, Goodrich retreader; Ray Jackson, Lameda Tire Company, and Mr. Peterson, retreaders; and Bob Winters, Atlos Rubber Grinders; all located in the greater Los Angeles area, July 1979.

EPA-287 (Cin.)
(4-76)

APPENDIX A

ASSUMPTIONS FOR THE COST ANALYSIS OF ASPHALT-RUBBER

TABLE 29

Interlayer costs of $.85/square yard are based on Idaho Transportation Department, Division of Highway costs for two projects.

Overlay costs are as follows (per square yard)

7" = 8.35
6" = 7.15
5" = 5.95
4" = 4.75
3" = 3.55
2" = 2.35

Source: Van Nostrand Reinhold Company, 1978 Heavy Construction Cost File, Unit Prices, New York, 1978.

The interlayer is .60 gal/square yard. The interlayer with 2-inch overlay costs $3.20/square yard, and with 4-inch overlay costs $5.60/ square yard.

FIGURE 25

The breakeven line is based on the overlay costs used for TABLE 29.

TABLE 30

The initial incremental investment is $.85/square yard.

The discounted payback periods are based on standard present value tables.

The Arizona maintenance costs cited in the text were $.21/year for the control surface, and $0.133/year for the asphalt rubber both over three years, and both in 1976$. They were adjusted to $.28/year and $.02/ year in 1978$ using the FMWA Construction Cost Composite Index. The difference in maintenance costs is thus $.26/year.

TABLE 31

The costs of overlays are:

1" = 1.15

1.5" = 1.75

2" = 2.35

3" = 3.55

4" = 4.95

Source: Van Nostrand Reinhold, op.cit.

The asphalt rubber seal coat is $1.10/square yard, and the conventional seal coat $.65/square yard, based on quoted prices from Arizona Refining Company.

FIGURE 26

The breakeven line is based on the overlay costs used in TABLE 31.

TABLE 32

The seal coat prices are as stated in TABLE 31, so the incremental investment is $.45/square yard.

The discounted payback periods are based on standard present value tables.

TABLE 33

Cracks are assumed to be 1" x 1", requiring 5.3 gallons per 100 linear feet.

The costs of the respective crack sealers, based on information supplied by Idaho Transportation Department are:

Flo Mix (contentional) @ .68/gal = 3.60/100 linear ft.

Asphalt-Rubber Mixed at Site @ .88/gal = 4.66/100 linear ft.

Asphalt-Rubber Prepackaged @2.61/gal =13.83/100 linear ft.

These costs in 1977$ were inflated to 1978$ using the Department of Commerce Refined Petroleum Products Index. Final costs were $3.75, $4.85, and $14.38. The incremental investment is $1.11 and $10.64/100 linear feet.

The discounted payback periods are based on standard present value tables.

TABLE 34

The breakeven cost ratios are derived from standard present value tables.

EPA-287 (Cin.)
(4-76)

TABLE 35

The weight of asphalt (and the asphalt-rubber mixture) is 8.42 lb/gal, based on 266 gal/metric ton.

The current price of asphalt is .34/gal, or $80/short ton of 235 gallons. Source: Charles R. Foster, "Effect of OPEC Price Increases on Future Price of Asphalt", National Asphalt Pavement Association, June 29, 1979.

The ARCO formulation is:

20% or 1.68 lb rubber
80% or 6.74 lb asphalt

The Sahuaro formulation is:

25% or 2.11 lb rubber
75% or 6.31 lb asphalt

ARCO's rubber price is 25¢/lb to which may be added 1¢ per pound freight costs; Sahuaro's rubber price is 6¢-15¢, also plus 1¢ per pound.

EPA-287 (Cin.)
(4-76)